An Assessment of Landscape Carrying Capacity for Waterfowl and Shorebirds in Nebraska's Rainwater Basin

A Conservation Effects Assessment Project Wildlife Component Assessment

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May 8, 2015

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EXECUTIVE SUMMARY

The Rainwater Basin (RWB) wetland complex in Nebraska provides critical spring-staging habitat for >7 million waterfowl and 500,000 shorebirds. While in the RWB, birds acquire energetic resources to replenish nutrient and lipid reserves to complete migration and initiate nesting. However, only 10% of the original RWB wetlands remain, causing decreased food and habitat availability for wetland-dependent birds. Conservation lands in the RWB, including private conservation programs (e.g., the Natural Resources Conservation Service's Wetlands Reserve Program [WRP]) and public lands (e.g., state Wildlife Management Areas), increase the accessibility of habitat and forage for waterfowl and shorebirds. This Conservation Effects Assessment Project was conducted to estimate the accessible forage resources on wetlands enrolled in WRP, on other conservation lands, and across the RWB landscape.

A map of vegetation communities present in all historical RWB wetlands in 2012 was created from aerial imagery and vegetation survey data. Vegetation communities were categorized as Agriculture, Bare Soil/Mudflat, Cattail, Cropped Wetland, Grass, Moist-Soil Species, Reed Canarygrass, River Bulrush, Water, Wet Meadow Species, and Woody Species. The accuracy of mapping natural vegetation communities was 75.0% overall.

Energetic resources accessible to waterfowl were estimated using a kilocalorie per acre (kcal/ac) rate for each habitat type based on the vegetation map communities. Energetic availability for waterfowl was calculated as the total potential forage production, assuming all wetland areas were ponded, as well as the actual, accessible annual energetic resources based on annual ponding data. Shorebirds were categorized into three foraging guilds including small-bodied probers/gleaners, large-bodied probers, and swimmers. Estimated accessible kilocalories for these guilds were calculated based on a rate of 10,238 kcal/ac and the percentage of each habitat type generally suitable for each guild.

Total potential forage resources available in 2012 for waterfowl, including all ponded and non-ponded areas, was 6.1 billion kcal, enough to meet the 4.4 billion kcal needed to sustain target waterfowl populations. Estimated mean kilocalorie accessibility based only on ponded wetland areas, however, was only 1.3 billion kcal, 3.1 billion kcal short of the target accessible forage for waterfowl. The 2012 estimated kilocalorie accessibility for the shorebird foraging guilds was 13.9 million kcal for small-bodied probers/gleaners, 29.4 million kcal for large-bodied probers, and 33.9 million kcal for swimmers. The accessible forage was sufficient to sustain the target swimmer population, but lacking 25.8 million kcal and 35.9 million kcal for the target small-bodied prober/gleaner and large-bodied prober populations, respectively.

Comparison of the 2012 vegetation map to a map of vegetation in 2004 indicated that the area of early successional habitat increased 560 ha in the entire RWB between 2004 and 2012, and 441 ha on WRP wetlands. Between 2004 and 2012, the total vegetative potential kilocalorie production for waterfowl increased by 228.8 million kcal, while the average ponded accessible forage for waterfowl increased by 131.9 million kcal. Active management actions in the RWB appeared to increase the accessible kilocalories for waterfowl. However, accessible forage for shorebirds was lower for all shorebird foraging guilds in 2012 than 2004 due to the loss of cropped wetland habitat between assessment years.

To adequately increase the area of accessible foraging habitats that provide the energetic resources to sustain target populations of waterfowl and shorebirds in the RWB, activities and programs should facilitate watershed restoration to increase water delivery to wetlands, wetland restoration, management to promote early successional habitat, and promotion of conservation programs to increase enrollment of wetlands into long-term conservation. Additionally, the use of the Agriculture Land Easement option within the Agriculture Conservation Easement Program to protect and restore cultivated wetlands would assist in meeting habitat goals.

INTRODUCTION

The Rainwater Basin (RWB) region of Nebraska is an important wetland complex in the Central Flyway for migratory wetland-dependent birds (Gersib et al. 1989, Gersib et al. 1992, North American Waterfowl Management Plan, Plan Committee 2012). The region covers 15,900 km^2, including parts of 21 counties, in the Loess Plains region of south-central Nebraska (Figure 1; Condra 1939). The landscape is characterized by deep wind-blown silt (i.e., loess) deposits, creating flat to gently rolling plains (LaGrange 2005). Interspersed across the plains is a high density of clay pan playa wetlands thought to be formed by wind (Kuzila 1984). The climate of the region is characterized by hot summers and cold winters. Average annual precipitation ranges from 56 cm in the western portion of the RWB to 76 cm in the eastern portion, but greatly varies seasonally and annually (Bishop et al. 2004). The wetlands receive water from direct precipitation and overland runoff, and are mostly temporarily, seasonally, or semi-permanently flooded.

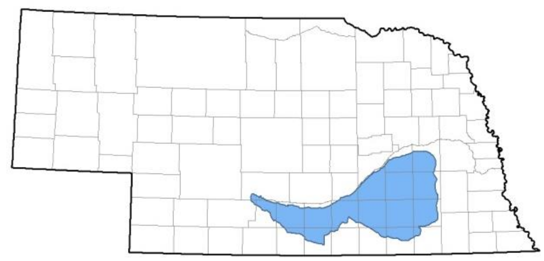

Figure 1. The Rainwater Basin Region of Nebraska, highlighted in blue.

Prior to settlement by European Americans, approximately 11,000 playa wetlands covered 83,000 ha in the RWB, based on an analysis of historical county soil surveys developed by the United States Department of Agriculture (USDA) Bureau of Soils (1901–1927) and Bureau of Soils and Chemistry (1927–1938), U.S. Fish and Wildlife Service (USFWS) National Wetlands Inventory (Cowardin et al. 1979), and the USDA Natural Resources Conservation Service's (NRCS) Soil Survey Geographic Database (Figure 2; Bishop and Vrtiska 2008). Of the 11,000 wetlands, approximately 1,000 were semi-permanently or seasonally flooded wetlands covering 27,000 ha, and 10,000 were temporarily flooded wetlands covering 56,000 ha. Individual wetland areas, termed historical wetland footprints, ranged in area from less than one to more than 400 hectares (LaGrange 2005).

RWB wetlands provide many important functions, one of which is providing habitat for migrating wetland-dependent birds. The RWB falls within the narrowest portion of the Central Flyway migration route (Figure 3), making RWB wetlands key stopover habitat for wetland-

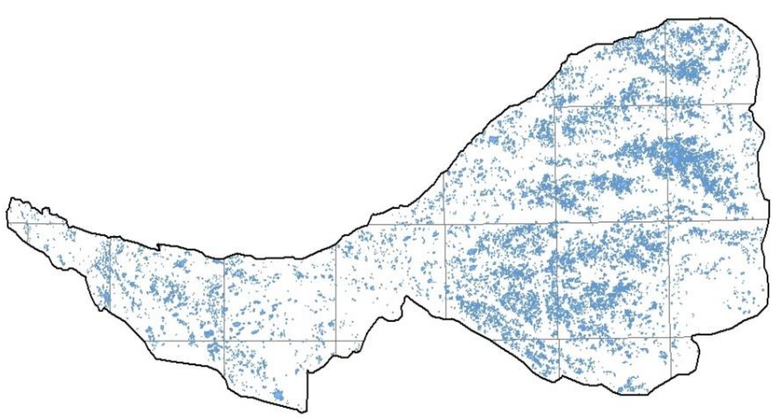

Figure 2. Historical wetland footprints (blue) in the Rainwater Basin region of Nebraska.

Figure 3. The Central Flyway. Dark gray represents the flyway, black Nebraska, and white the Rainwater Basin.

dependent birds to replenish their energy and nutrient reserves, particularly as they migrate north in the spring. Each spring, >7 million waterfowl stopover in the RWB, including 50% of the mid-continent Mallards (*Anas platyrhynchos*), 50% of mid-continent Lesser Snow Geese (*Chen caerulescens*), and 30% of the continental Northern Pintail (*A. acuta*) breeding population (Table A.1; Benning 1987, Gersib et al. 1989, Vrtiska and Sullivan 2009). RWB wetlands also provide stopover habitat for an estimated 500,000 individuals and 40 species of shorebirds (Table A.2; RWBJV 2013*b*) as well as the endangered Whooping Crane (*Grus americana*; Tacha et al. 2010, RWBJV 2013*c*).

Since European settlement, RWB wetlands were drained and filled to increase cropland area, which significantly reduced the amount of wetland habitat. This conversion was facilitated by early USDA farm programs, road construction, and improvements to earth-moving machinery after World War II. During that time, an estimated 90% of RWB wetlands were destroyed or highly degraded, constituting 88% of the original wetland area (Schildman and Hurt 1984). Additionally, virtually all of the remaining wetlands were hydrologically impacted, which reduced their area and functionality (Schildman and Hurt 1984, Smith 1998). Many of the wetlands were also impacted by the accumulation of culturally-accelerated sediment (LaGrange et al. 2011). Because of the resulting wetland loss and degradation as well as the region's importance to wetland-dependent birds, the RWB was recognized as habitat of major concern in the 1986 North American Waterfowl Management Plan (Canadian Wildlife Service and U.S. Fish and Wildlife Service 1986) and listed as containing high priority wetlands in the Nebraska Wetlands Priority Plan (Gersib 1991, LaGrange 2005).

The loss of RWB wetlands has decreased food and habitat resources available for migrating wetland-dependent birds and increased the density of individuals on remaining wetlands. Higher bird densities can intensify intra- and inter-specific competition and may increase the frequency of aggressive behavior. This may result in limited time available for feeding, which may lead to reduced energy and nutrient reserves (Krapu 1974, Gersib et al. 1989, Webb et al. 2010). Females with lower nutrient reserves may delay nesting, lay smaller clutches, or forego re-nesting if the initial clutch is lost, ultimately decreasing recruitment (Krapu 1981, Dubovsky and Kaminski 1994, Devries et al. 2008). Although waste grain found in the adjacent croplands is available for waterfowl, naturally occurring wetland seeds, and possibly invertebrates, are necessary in waterfowl diets to offset the mineral and protein deficiencies in waste grain (Loesch and Kaminski 1989, Reid et al. 1989, Pearse et al. 2011).

Exacerbating increased competition due to habitat loss, some waterfowl populations have been increasing in recent decades. The mid-continent population of Lesser Snow Geese and Ross's Geese (*C. rossii*) has increased an average of 7% per year between 2005 and 2014 (U.S. Fish and Wildlife Service 2014). Also, the total North American breeding duck population estimate in 2014 was 43% higher than the long-term average between 1955 and 2013, implying that populations migrating through the RWB are also greater than the long-term average (U.S. Fish and Wildlife Service 2014). The increased number of waterfowl using RWB wetlands may lead to further competition for limited food and space resources.

Although the loss of RWB wetlands has potential to lower wetland-dependent bird carrying capacity at this major migration stopover site, the rapid loss of wetlands in the region did not slow until the latter half of the 1900s as people began to recognize the importance of wetlands. By 1960, the USFWS recognized the RWB as critical migratory bird habitat and acquired its first Waterfowl Production Area (WPA) in the region when it obtained Massie WPA in 1963. In 2012, the USFWS owned and managed 59 WPAs, covering 9,600 ha. By the same year, the Nebraska Game and Parks Commission (NGPC) owned 35 Wildlife Management Areas (WMA) that contained 3,600 ha. The management of WPAs and WMAs is often intensive because of the anthropogenic factors, such as culturally-accelerated sedimentation and altered hydroperiods (LaGrange et al. 2011), that impact the wetlands. Also, the vegetation communities in RWB wetlands can rapidly transition from desirable, early successional species to monocultures of invasive species, such as reed canarygrass (*Phalaris arundinacea*), narrow leaf cattail (*Typha angustifolia*), and river bulrush (*Schoenoplectus fluviatilis*), which provide little foraging habitat for waterfowl and shorebirds. To better manage WPAs and WMAs, both the USFWS and NGPC have slowed the number of acquisitions to focus efforts on maximizing habitat on existing public lands.

Federal legislation helped offset the large amount of wetland loss and degradation with key laws such as the 1972 Clean Water Act, the "Swampbuster" provision of the 1985 Food Security Act, and the 1989 North American Wetlands Conservation Act. The 1990 Food, Agriculture, Conservation, and Trade Act was also an important piece of legislation as it allowed Congress to authorize the Wetlands Reserve Program (WRP).

The purpose of WRP was to restore, protect, and enhance wetlands in the United States (NRCS 2014). The WRP was a USDA program administered by the NRCS under which landowners voluntarily enroll marginal lands with degraded wetland features into a 10-year restoration agreement, 30-year easement, or perpetual easement. The program's goal was to achieve the greatest wetland functions and values, along with optimum wildlife habitat, on every acre enrolled (NRCS 2014). NRCS completed restoration of wetland and upland areas, provided financial assistance, and continues to provide technical assistance. Ownership was maintained by the private landowner, who remains responsible for managing the site. After 1996, an emphasis was placed on restoring wetland hydrology and topography to ensure maximum wildlife benefits, particularly for migratory birds.

WRP sites in the RWB provide multiple benefits for landowners and migratory birds. Through Compatible Use Authorization, landowners are often able to graze properties to integrate WRP tracts into their farm and ranch operations while actively managing the wetlands for optimal waterfowl habitat. The juxtaposition of the WRP sites complements other adjacent wetlands, both public and private, creating wetland complexes for migrating wetland-dependent birds (Webb et al. 2010, Tidwell et al. 2013). In 2012, the RWB contained 120 WRP easements that covered 3,198 ha, of which 103 (86%) were in long-term (i.e., ≥30-year) easements, covering 2,536 ha.

To better understand programs such as WRP, the Conservation Effects Assessment Project (CEAP) was created in 2006. CEAP is a multi-agency effort to quantify the environmental benefits of and develop the science base for managing USDA conservation programs, such as the Conservation Reserve Program, WRP, and the Environmental Quality Incentives Program.

This CEAP assessment was conducted by the Rainwater Basin Joint Venture (RWBJV) partners to monitor both site- and landscape-scale habitat conditions and carrying capacity for waterfowl and shorebirds. Site-scale monitoring was completed using vegetation surveys, while landscape-scale assessment was done using remote sensing software to create a vegetation map for all historical wetlands in the RWB. The vegetation map was then used in conjunction with published literature of energetic resources to estimate accessible forage resources in RWB wetlands for waterfowl and shorebirds. Agricultural waste grain in the RWB region is sufficient to meet all energetic requirements for waterfowl; however, waste grain should constitute no more than 72% of energetic requirements for waterfowl because it lacks nutrients that are found in natural wetland foods (Loesch and Kaminski 1989, Reid et al. 1989, Bishop and Vrtiska 2008). Our assessment focused solely on the energetic production by wetland sources due to the lack of waste grain in shorebird diets, the importance of wetland seeds in waterfowl diets, and the abundance of waste grain in the region.

This assessment also provides new insight into the accessible forage resources programmatically and by ownership (i.e., conservation property types). Understanding the contribution of different components of conservation lands is important because the quality of habitat can influence wetland use by migratory birds and other wildlife. For example, early successional vegetative communities provide the greatest energetic production per acre for migratory waterfowl (Bishop and Vrtiska 2008, RWBJV 2013*d*). Understanding habitat conditions across conservation lands provides the RWBJV partners information necessary to prioritize management across the region to promote desirable vegetation communities.

A similar vegetation map was generated in 2004 and comparison between the 2004 vegetation map and the one generated in this CEAP provides new insight into the changes of vegetation communities in the RWB. In 2009, the RWBJV partners implemented a vegetation management initiative to reduce the distribution and abundance of invasive species (i.e., reed canarygrass, cattail, and river bulrush). Since implementation of the management initiative, RWBJV partners have conducted active management (e.g., chemical, mechanical) on 1,215–2,025 ha annually on both public and private lands. Our assessment provides the first evaluation of the effectiveness of these management actions across the landscape and the impacts of these activities on landscape carrying capacity for waterfowl.

In addition to prioritizing management, the RWBJV partners plan to use the vegetation map and data generated by this CEAP to develop decision support tools to guide future private lands delivery and site-level management plans for WRP easements in the RWB. All of these actions will help guide management decisions as well as programmatic planning at the landscape-scale to ensure sufficient forage resources are accessible for wetland-dependent migratory birds using RWB wetlands.

This CEAP report provides information about (1) wetland vegetation surveys conducted on WRP, other long-term private easements (i.e., easement properties held by Ducks Unlimited, Inc. [DU], USFWS, and Natural Resources Districts), state WMAs, and USFWS WPA properties; (2) the vegetation map created for all historical wetlands in the RWB; (3) the estimated kilocalorie accessibility of foods for waterfowl and shorebirds in the RWB; and (4) a comparison between the 2004 and 2012 vegetation maps.

METHODS

Imagery Acquisition

To develop the 2012 habitat assessment, we acquired and used three different sets (i.e., spring, mid-summer, and late-summer) of aerial photography covering the RWB. Color infrared aerial photographs were acquired by Cornerstone Mapping (Lincoln, Nebraska) from 1–15 March, 2012, (i.e., spring), as well as 1–10 August, 2012, (i.e., late-summer). For each set of images, the RWBJV was supplied the raw color-infrared images and image acquisition geometry, including X, Y, Z coordinates as well as exterior orientation (i.e., phi, omega, and kappa measurements of the aircraft at acquisition). After acquisition, the images were color-balanced so color tone and hue matched within the image sets. Acquisition geometry and exterior orientation data were then used to orthorectify the individual images. Once the images were orthorectified, county-wide mosaics were created. Color balancing was completed using OrthoVista 4 (Inpho GmbH, Stuttgart, Germany), while the orthorectification and mosaicking were completed using ERDAS Leica Photogrammetry Suite 11 (ERDAS, Inc., Norcross, Georgia). The third aerial imagery layer used for analysis was true color imagery obtained in July 2012 (i.e., mid-summer) and processed by the Farm Service Agency. Lastly, we obtained July 2010 true color imagery from the Farm Service Agency, which were used to create field survey points because the July 2012 imagery was not yet available.

Survey Point Creation – Private Conservation Lands

After processing the spring imagery, we created survey points to collect field vegetation data in historical wetland footprints. To create survey points, we developed polygons within the wetlands using eCognition Developer 8 (Trimble Germany GmbH, Munich, Germany). This program uses image object orientated processing to aggregate pixels that have similar color and texture. The resulting image object polygons generally contain similar vegetation communities. Because neither mid- nor late-summer imagery were available for 2012, we relied on 2012 spring imagery and the most recent (i.e., 2010) mid-summer imagery from the Farm Service Agency. We loaded the historical wetland footprints shapefile and imagery into eCognition 8, where the historical wetlands shapefile was set as the thematic layer by conducting a chessboard segmentation with an exaggerated scale parameter. Within the wetlands, eCognition 8 segmented by grouping similar pixels together based on imagery pixel values and neighborhood context, using multiresolution image object segmentation.

Polygons were then exported from eCognition 8 into ArcMap 9 (ESRI, Redlands, California), in which 3,000 polygons were randomly selected without replacement using Hawth's Tools from 125 wetlands under 10-year and long-term WRP easements as well as other long-term private easements. The number of selected polygons was stratified on a per county basis based on the relative percentage of the private conservation lands within the county. To determine the location of each survey point, we used ArcMap 9 to generate a point at the centroid of each of the 3,000 sample polygons, ensuring the centroids fell within the polygons (Figure 4). Using ArcPad 10 (ESRI, Redlands, California), the survey points were uploaded into Trimble GeoXT 2005 Series Global Positioning System (GPS) units (Trimble Navigation, Ltd., Sunnyvale, California).

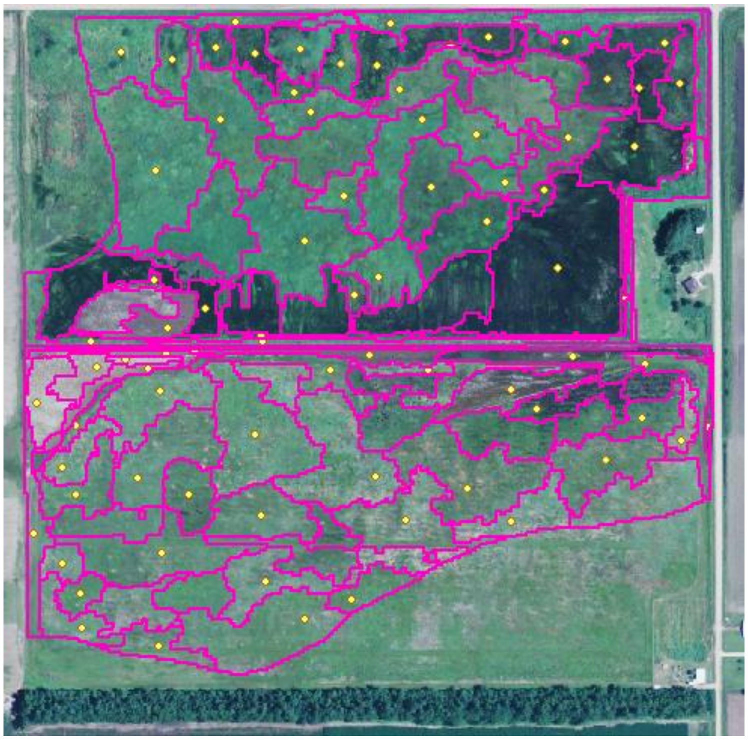

Figure 4. Vegetation survey points at two Wetlands Reserve Program sites in the Rainwater Basin, Nebraska. Pink lines indicate polygon outlines and yellow points indicate vegetation survey points.

Survey Point Creation – Public Conservation Lands

To maximize sampling effort, we also used vegetation survey points collected on public lands that had been previously created for a separate project designed to help the RWBJV partners better understand vegetation community response to active management. Initial monitoring was completed along 50-m transects based on the 2004 vegetation map and created to describe all vegetation communities under different management on public lands (Bishop et al. 2004). The number of transects established in each management zone was determined based on its area, with larger management zones containing more transects. In 2009, the sampling transitioned away from the 3,690 transects and adopted an ocular monitoring protocol using a modified 1-m^2 sampling frame (Daubenmire 1959) to maximize sampling effort. The 2009 survey points were located at the endpoint of transects and additional survey points were randomly placed where new management zones had been created. Annually between 2010 and 2012, additional survey points were randomly placed in management zones to provide survey points across the entire historical hydric soil footprint and ensure sampling in new management zones. In 2012, a total of 9,732 points were planned for sampling on public lands. The points were then uploaded into Garmin GPSMAP 76 and Garmin GPS 75 (Garmin International Inc., Olathe, Kansas) GPS units.

Field Data Collection and Management

Field vegetation surveys were conducted between 27 August and 9 November, 2012. We used a GPS unit to navigate to a point, where we placed a 1-m^2 sampling frame. At each point, we recorded the percentage range of each vegetation cover type within the frame using a modified Daubenmire cover class (Daubenmire 1959; Table 1). Cover types were based on a predetermined list of 37 species and groups of species chosen based on their commonness (e.g., ragweed [*Ambrosia* spp.]) and importance to wetland management (e.g., phragmites [*Phragmites australis*]; See Table A.3 for a complete list of cover types).

Once surveys were completed, all of the private easements survey data were loaded directly from the GPS units into the corresponding shapefile using ArcPad 10 and public lands data were manually entered from datasheets into Microsoft Access 2007 (Microsoft Corporation, Redmond, Washington). Using a combination of Microsoft Access 2007 and Microsoft Excel 2007 (Microsoft Corporation, Redmond, Washington), we converted the raw data into a usable format based on unique point identifiers. Because of the descriptive nature of range values, the cover classes were transformed and relativized. We first transformed all percentile ranges to the range midpoints. Because the sum of all midpoints at a survey point seldom equals 100%, data were relativized to ensure that each point was equally weighted in the analysis. To relativize the data, the midpoints for all vegetation cover types at a survey point were summarized and each midpoint was divided by the sum of the observations within that point. For example, a plot with reed canarygrass cover class five (75–95%), annual smartweeds (*Polygonum* spp.) cover class two (5–25%), and barnyardgrass (*Echinochloa* spp.) cover class two (5–25%) would be assigned midpoints of 85%, 15%, and 15%, respectively. The midpoints would total 115% total cover, so the midpoint of each observation would be divided by 115, resulting in 74% reed canarygrass, 13% annual smartweeds, and 13% barnyardgrass.

Table 1. Daubenmire cover classes (Daubenmire 1959).

Daubenmire Cover Class	Cover Class Range (%)	Cover Class Midpoint (%)
1	0 – 5	2.5
2	5 – 25	15.0
3	25 – 50	37.5
4	50 – 75	62.5
5	75 – 95	85.0
6	95 – 100	97.5

Segmentation and Assigning Testing and Training Data

When the 2012 spring, mid-summer, and late-summer imagery were ready for analysis, we segmented all wetlands in the historical wetlands shapefile. We used the same procedure as the previous segmentation, setting the historical wetlands shapefile as the thematic layer and conducting a multiresolution image object segmentation within the wetlands using eCognition 8. However, we used all three 2012 image sets instead of the 2012 spring and 2010 mid-summer imagery. The resulting wetland image object polygons served as the basic units for all subsequent classification with the assumption that similar groups of pixels had similar dominant vegetation communities. Polygons were exported from eCognition 8 and loaded into ArcMap 10, where we assigned each polygon a unique identifier. The unique polygon identifiers were joined to the survey point shapefile using a spatial join.

In Microsoft Access 2007, we opened the attribute table of the survey point shapefile and the relativized field data. The unique polygon identifiers were added to the field data based on the unique point identifiers. The relativized field data, including unique polygon identifiers, were used to determine the map class each polygon represented. The map classes were categorized as Bare Soil/Mudflat, Cattail, Grass, Moist-Soil Species, Reed Canarygrass, River Bulrush, Water, Wet Meadow Species, and Woody Species. These map classes were an aggregation of the 37 different vegetation cover types used to describe vegetation in the field (see Table A.3 for each cover type's associated map class). We assigned the vegetation cover types their associated map class and aggregated the midpoints of each map class in every polygon to convert the relativized point data into each polygon's final map class. Using Microsoft Excel 2007, a series of queries were conducted to determine the polygon's dominant map class, which was assigned to the polygon. If two or more map classes tied, the polygon was assigned "Mixed."

The polygon map classes were joined to the segmented polygon shapefile in ArcMap 10. Next, surveyed polygons were defined as either training data or testing features. Training polygons were used during remote sensing to teach eCognition 8 the spectral signatures of each class. Testing polygons were used to assess the accuracy of the final vegetation map. To determine the number of polygons needed for training data, the following formulae from Congalton and Green (1999) were used:

$$n = B \times \prod_i \times (1 - \prod_i) / b_i^2$$

and

$$B = \chi^2_{(1,\alpha/k)}$$

where:

n = number of samples,
$\prod_i$ = percentage of the map area covered by the class, based on field data,
b_i = precision,
α = confidence level,
k = number of classes.

To effectively complete the supervised classification in eCognition 8, polygons that were most dominated by a class were selected as training data. We did so by randomly selecting polygons that were ≥75% dominated by one map class and then, if needed, we randomly chose from polygons containing 70–74% of the class. When possible, we also set the minimum number of testing polygons equal to n. If we had more than enough polygons with >50% dominance to set both the minimum number of training and testing polygons to n (i.e., $>2n$), then any extra polygons that had ≥75% dominance were assigned as training polygons as well. The remainder of the polygons with >50% dominance was assigned as testing polygons. No polygons with ≤50% dominance were used as training or testing polygons.

Remote Sensing: Classification and Final Vegetation Map

Classification of Vegetation Communities

To complete classification of the wetlands, the 2012 spring, mid-, and late-summer aerial imagery were loaded into eCognition 8, along with the segmented wetlands shapefile. We used a chessboard segmentation to set the wetland polygons as the thematic layer. The training polygons were assigned their appropriate map class and set as samples using the classified image objects to samples tool. We then conducted a supervised classification, which assigned a class to each polygon based on the spectral signatures of the pixels contained within the training polygons. We set the parameters used for classification to the mean pixel value of each of our nine imagery bands, the standard deviation of each band, the maximum difference between imagery bands, and the brightness within each polygon. These 20 parameters were used to assign a map class to all polygons, including testing polygons.

The classified polygons were exported from eCognition 8 into ArcMap 10. We added a text field called "Vegetation" in the corresponding shapefile and imported it as a feature class into a geodatabase we had previously made in ArcCatalog 10, in which we created a domain containing the map classes and applied it to the Vegetation field. The domain provided a dropdown list from which to choose a map class and thereby reduce data entry errors. The classified polygons, training data, aerial imagery, and Light Detection and Ranging (LiDAR) elevation data were uploaded into ArcMap 10. We used these datasets to manually verify that map classes were accurately assigned to each polygon based on the imagery, surrounding vegetation communities, training data, elevation, and knowledge of spectral signatures. We also created the class "Agriculture" and assigned it to all cultivated polygons based on aerial imagery.

The manual verification was completed a second time only on testing polygons, which were then extracted and saved as a shapefile to be used later for accuracy assessment. Prior to our second round of manual verification for all non-testing polygons, we reclassified all surveyed polygons, including testing polygons, to their field-verified map class. Polygons that contained an equal proportion of two or more classes (i.e., Mixed polygons) were manually set to one of the tied classes based on imagery and adjacent vegetation communities. We then manually verified every polygon again using the same procedure as the first round of verification, except we used all the field-surveyed polygons as references to increase accuracy of the vegetation map.

We also increased our accuracy by reclassifying the field-surveyed polygons that were initially classified as Bare Soil/Mudflat but overlapped an area that had been disked for vegetation management purposes after imagery acquisition but prior to field data collection. These polygons were reclassified because the Bare Soil/Mudflat class may have only reflected the disking and not the class that was present at the time the imagery was acquired. The disked areas were determined based on a management dataset that tracked all active management activities conducted by DU, NGPC, RWBJV, and USFWS in the RWB. We first checked the 2012 mid-summer aerial imagery to determine if actively growing vegetation was present or the area should be classified as Bare Soil/Mudflat. If it should have been classified as something other than Bare Soil/Mudflat, we determined its classification using a combination of other vegetation types present in 2012 surveys and data collected during 2013 vegetation surveys. For example, if a polygon contained 25–50% cattail and 50–75% bare soil or mudflat in the 2012 survey, the polygon was classified as Cattail. If no other cover types were listed in the 2012 survey, we classified the polygon based on the 2013 surveys.

Incorporation of Irrigation Reuse Pits

We incorporated irrigation reuse pits into the vegetation map to more closely match the 2004 vegetation map by first uploading a shapefile containing all irrigation reuse pits in the RWB (RWBJV 2012). Irrigation reuse pits filled with soil as part of the RWBJV Watershed Restoration Initiative were erased from the dataset. The irrigation reuse pits were then integrated into the vegetation map shapefile using an identity overlay, setting the wetland vegetation polygons as the input features and irrigation reuse pits as the identity features. A new text field labeled "Pit" was created and polygons were classified as a pit or not.

Identification of Cropped Wetlands

Hydrological modifications were made in many historical wetlands so they could be planted to row crops. The more significantly modified sites rarely pond water and have little to no wetland functionality. In highly modified cultivated wetlands, herbicide applications and conventional cultivation practices significantly reduce germination and growth of plant species other than row crops. However, the less impacted wetlands seasonally flood, producing a flush of annual species such as smartweeds and barnyardgrass. The RWBJV has long recognized the value of cultivated wetlands that flood often, whether annually or every few years, as important habitat for waterfowl and shorebirds, and attempted to incorporate these habitats into planning and conservation delivery activities. These often-ponded, cultivated wetlands have been termed "cropped wetlands" to distinguish them from cultivated areas that were historical wetlands but no longer, or very rarely, exhibit wetland characteristics.

Unfortunately, cropped wetlands are difficult to distinguish using traditional remote sensing techniques and a single year of imagery. The difficulties are compounded when the region is experiencing average to below average precipitation, such as in 2012, and irrigation promotes vigorous crop growth. Vigorous crop growth in the wetland footprint eliminates wetland spectral signatures because the growing crops have a homogenous spectral signature. To effectively identify cropped wetlands, we used the ponded areas identified in the Annual Habitat Survey (AHS) assessments (Bishop et al., RWBJV, in review).

The AHS assessments began in 2004 and were completed annually from 2006 to 2012. Each year, color infrared imagery collected over a majority of the RWB at the peak of spring migration (e.g., 27 February–14 March, 2006) was analyzed to identify ponded areas, natural vegetation, and nonfunctional historical wetland footprints. To most effectively describe and identify the extent of cropped wetlands versus sheet-water in row crop fields, the eight years of AHS data were analyzed together. Cropped wetlands were defined as those hydric soils in agricultural fields that displayed ponded conditions ≥25% of the time during the assessment period.

To establish the areas of cropped wetlands, we first had to determine the number of years wetlands were surveyed for AHS analysis. In 2004, the RWBJV developed a flight plan to maximize wetlands photographed with the least number of images collected. However, the flight block was redefined in 2006 to capture nearly the entire RWB landscape (92%) and has been consistently used since (Bishop et al., in review). To determine the number of years a wetland was surveyed, the spatial extent of each AHS shapefile was combined into a single dataset using a union overlay. In the attribute table, we added a field defining the number of years the geometry was surveyed. The Years Surveyed Shapefile was converted to a raster, using the number of years surveyed as the raster value.

For each AHS year, a ponded area layer was developed by creating a field in the shapefile and assigning a one to ponded areas and a zero to non-ponded areas. Each year's AHS ponded area shapefile was converted to a raster, using the binary ponded field as the raster value. The binary AHS ponded rasters were added together using the raster calculator to create a Ponded Years Raster. In the Ponded Years Raster, the value reported by each pixel represented the number of years ponded water was observed at that location.

Identification of cropped wetlands required several steps. First, we divided the Ponded Years Raster by the Years Surveyed Raster to create a Proportion Years Ponding Raster. The Ponded Over 25% Raster was developed by reclassifying the Proportion Years Ponding Raster so values <0.25 and “no data” became zero and values ≥ 0.25 were recoded to one. The Ponded Over 25% Raster was converted to a shapefile. We exported all of the Agriculture polygons from the vegetation map and then all of the remaining, natural vegetation polygons as two separate shapefiles. We integrated the Ponded Over 25% Shapefile into the Agriculture map class using an identity overlay with the input feature set as the exported Agriculture polygons and the identity feature set as the Ponded Over 25% Shapefile. We selected all polygons that were ponded ≥25% of the time and changed the map class to Cropped Wetland. We then dissolved by the Vegetation, Pit, and unique polygon identifier fields. All polygons $<25\ m^2$ were merged with adjacent polygons using the eliminate tool. Finally, we merged the Agriculture and Cropped Wetland shapefile with the natural vegetation shapefile to recombine the vegetation map.

Definition of Habitat Type

The energetic resources available for waterfowl and shorebirds vary by habitat type (i.e., early successional, late successional, cropped wetland, and upland habitats). To characterize the energetic resources, several map classes were aggregated to define the different habitat types. The early successional habitat type was comprised of the map classes Bare Soil/Mudflat, Moist-Soil Species, Water, and Wet Meadow Species, that were not overlapping an irrigation reuse pit, and were estimated to produce 250,000 kcal/ac, based on a literature review of the habitat type’s plant seed production and energy provided by those seeds (Bishop and Vrtiska 2008). The late successional habitat type included the Cattail, Reed Canarygrass, and River Bulrush map classes as well as irrigation reuse pits. This habitat type was estimated to provide 25,000 kcal/ac (Bishop and Vrtiska 2008). The cropped wetlands habitat type was assigned to the Cropped Wetland map class, when not overlapping an irrigation reuse pit, and was estimated to produce 100,000 kcal/ac (Bishop and Vrtiska 2008). Upland habitats included the Agriculture, Grass, and Woody Species map classes and were estimated to produce no kilocalories for waterfowl. In ArcMap 10, a Succession field was added to the vegetation map and populated with “Early”, “Late”, “Cropped”, or “Upland”, as appropriate.

Topology Maintenance

To remove slivers caused by integration of the irrigation reuse pits and identification of cropped wetlands, the eliminate tool was used to merge all polygons $<25\ m^2$ with a neighboring polygon. After the eliminate function was completed, we verified that all remaining polygons $<25\ m^2$ were not topologically adjacent to other polygons, and deleted them. To further clean our dataset, we repaired geometry to delete polygons with null geometry and corrected topology errors. Once the topology maintenance was completed, we reduced the number of features in the vegetation map by dissolving based on vegetation type and the presence of irrigation reuse pits. In both the dissolved and undissolved vegetation maps, area was calculated for each polygon.

Integration of Conservation Lands

To determine the vegetation communities within each long-term conservation property type, we conducted an identity overlay with the final, undissolved vegetation map used as the input feature and the long-term conservation lands shapefile as the identity feature. The RWBJV conservation lands shapefile tracks program delivery and ownership. Because sites could be considered more than one property type (e.g., a WRP easement owned by the USFWS), we set a hierarchy for which the order of precedence, from high to low, was WMA and WPA properties, long-term WRP easements, then other long-term private conservation easements. The area of polygons was recalculated. All polygons intersecting long-term conservation land boundaries were selected and the attribute table was exported and uploaded in Microsoft Excel 2007. Pivot tables were created to determine each class' surveyed area for all property types. The vegetation map with the identity of property boundaries was not incorporated into the final vegetation map and was not included in the geodatabase available for public download.

Accuracy Assessment

We used the previously saved shapefile of testing polygon data that included each polygon's field-verified class, twice-verified vegetation map class, and area to conduct the accuracy assessment. In ArcMap 10, we selected all testing polygons and exported the attribute table as a dBASE file. We imported the file to Microsoft Excel 2007, where we calculated our overall accuracy as well as the producer and user accuracy for each class. Producer accuracy was calculated as the area correctly assigned to a class divided by the field-verified area of the class. For example, a high producer accuracy of Water indicates that most of the polygons that should be classified as Water were classified correctly. However, additional polygons that were not Water may also be classified as Water. User accuracy was calculated as the area correctly assigned to a class divided by the total area of that class in the vegetation map. High user accuracy of Water indicates that if a polygon was classified as Water, it was very likely water. However, not all water polygons were necessarily classified as Water.

The accuracy of non-surveyed natural vegetation (i.e., all map classes except Agriculture and Cropped Wetland) polygons was calculated as the area of correctly classified polygons for all classes divided by the total testing area. The accuracy of all surveyed polygons was assumed to be 100%. To calculate the accuracy of surveyed areas and the overall accuracy, we determined the area of surveyed polygons, natural vegetation in the entire map, and natural vegetation on surveyed properties using the Statistics tool in ArcMap 10. We then calculated the percent, by area, of all surveyed and non-surveyed natural vegetation in the overall map and surveyed properties. The surveyed property accuracy and overall accuracy were calculated as Accuracy = (%Surveyed area × %Surveyed accuracy) + (%Non-surveyed area × %Non-surveyed accuracy).

Comparison of Habitat between 2004 and 2012 Vegetation Maps

Coarse and fine scale assessments were completed to evaluate vegetation community shifts at the landscape scale. At the coarse scale, we simply compared total area, by map class, between the 2004 and 2012 maps. At the fine scale, we compared the number of historical wetland footprints that contained >0.2 ha of hydrophytic communities and/or irrigation reuse pit(s). For both the coarse and fine scale assessments, we evaluated the distribution of cropped wetlands across the landscape by comparing the total area and number of footprints containing >0.2 ha of cropped wetlands between the 2004 and 2012 vegetation maps using the Cropped Wetland identifications derived from the AHS data. At the coarse scale, we also compared the Cropped Wetland identifications in the 2012 and 2004 vegetation maps to the Stressed Agriculture identifications that were completed as part of the 2004 assessment.

To compare the number of wetland footprints containing hydrophytes, we defined hydrophytic communities as all natural vegetation map classes dominated by wetland vegetation. The Grass and Woody Species map classes were considered to be non-functional wetland areas since they were mainly dominated by upland vegetation. Thus, hydrophytes included Bare Soil/Mudflat, Cattail, Moist-Soil Species, Reed Canarygrass, River Bulrush, Water, and Wet Meadow Species. Because pits generally provide only deep water habitat and limited forage resources, they were assessed separately.

For the fine scale assessments, we first had to conduct an identity overlay, dissolve, and eliminate to integrate the cropped wetlands into the 2004 vegetation map using the same methods outlined for incorporating the cropped wetlands into the 2012 vegetation map. We then incorporated the unique wetland identifying number used to describe each hydric soil footprint using identity overlays in which we set the input feature as the 2004 or 2012 vegetation map containing cropped wetlands and the identity feature as the historical wetlands shapefile. Incorporating the unique identifiers allowed us to evaluate shifts in wetland function by footprint between the 2004 and 2012 assessment years. The areas of polygons were then calculated. The attribute tables for the 2004 and 2012 vegetation maps were loaded into Microsoft Excel 2007. We used pivot tables to determine each wetland footprint's total footprint area, area of hydrophytic communities, whether the footprint contained a pit, and the area of cropped wetland habitat. We then calculated the number of footprints containing an irrigation reuse pit; >0.2 ha of hydrophytic communities; >0.2 ha of cropped wetland habitat; and by footprint area, >0–25%, >25–50%, >50–75%, and >75% hydrophytic communities for footprints containing over 0.2 ha of hydrophytic communities.

The number of footprints containing <0.2 ha of hydrophytes were not assessed due to changes in methods used to generate the different vegetation maps. The 2004 vegetation map contained larger polygons ($\overline{x}$ = 0.80 ha) than the 2012 map ($\overline{x}$ = 0.64 ha). Because of the smaller polygon size, more small areas of hydrophytic communities (e.g., road ditches) could be mapped in 2012, increasing the number of wetland footprints containing a very small area of hydrophytes. We set the minimum area of hydrophytic communities to 0.2 ha to account for the different polygon sizes.

Because the 2004 and 2012 vegetation maps were generated using slightly different methods and techniques, we modified the map classes to congruently compare habitat at the coarse scale between assessment years. The 2004 map contained the class Water Mudflat, which also included bare soil, and had Pits as its own map class instead of a separate field in the attribute table. Given that, we combined Bare Soil/Mudflat and Water into Water Mudflat and selected all pits in the 2012 map's table and changed the vegetation class to Pit. The 2004 map also contained both Agriculture and Stressed Agriculture map classes, while the 2012 map had Agriculture and Cropped Wetland. To compare similar classes, we set the 2004 Cropped Wetland map class to the cropped wetlands that we previously integrated into the 2004 vegetation map and set all remaining cultivated polygons as simply Agriculture. Pivot tables were then created to summarize the area of each class for 2004 and 2012.

To understand how habitat conditions have changed on conservation lands, summaries were tallied to describe total map class area by category. We used an identity overlay to combine the 2004 vegetation map and property boundaries of long-term conservation lands shapefile to create an output similar to the one created using the 2012 vegetation map. Property types were verified between 2004 and 2012 to ensure no properties transitioned from one property type to another between assessment years (e.g., a tract enrolled in long-term WRP before 2004 that became a WPA in 2008). The polygons on conservation lands for the given year were selected in each of the vegetation maps, and the attribute tables were exported. Within every property type, we then calculated each class' percentage of the wetland area. The property type's wetland area was set to the area of wetlands that were in the long-term conservation lands for the given year. For example, a wetland initially enrolled in WRP in 2005 was not included in the WRP wetland area for the 2004 vegetation map, but was included in the WRP wetland area for 2012.

The final coarse scale assessment consisted of comparing the area of the Cropped Wetland map class in the 2004 and 2012 vegetation maps to the Stressed Agriculture map class in the 2004 vegetation map. As part of the 2004 assessment, the Stressed Agriculture map class was defined as portions of agriculture fields, within a hydric soil footprint, that exhibited a stressed vegetation signature (i.e., natural hues [e.g., brown, yellow, light green] compared to the vibrant green hues associated with actively growing row crops). The comparison of 2004 and 2012 Cropped Wetland to 2004 Stressed Agriculture also provided a unique opportunity to compare results between a snapshot assessment (i.e., single acquisition year) to the identifications developed from a long-term dataset. To do so, we summarized the area of the Cropped Wetland map class in the 2012 vegetation map and the modified 2004 vegetation map as well as the area of the Stressed Agriculture map class in the original 2004 vegetation map.

Kilocalorie Accessibility for Waterfowl between Vegetation Assessment Years

Total Potential Forage Production for Waterfowl

The amount of energy (i.e., kilocalories) accessible for waterfowl in RWB wetlands is dependent on wetland vegetation and the area of these communities that are ponded (Bishop and Vrtiska 2008, RWBJV 2013*a*, RWBJV 2013*d*). At the landscape scale, total potential kilocalorie production in 2004 and 2012 was calculated using the total area of early successional, late successional, and cropped wetland habitats, effectively simulating all areas were ponding water and therefore providing foraging habitat for waterfowl. For the 2012 vegetation map, habitat types were defined as outlined previously and stored in the Succession field. In the 2004 map, Moist-Soil Species, Wet Meadow Species, and Water Mudflat map classes were aggregated into the early successional habitat type; Cattail, Reed Canarygrass, River Bulrush, and Pit map classes were aggregated under the late successional habitat type; and the cropped wetland habitat type was defined based on the AHS cropped wetlands. Once the habitat types were defined, total area, in acres, for each habitat type was summarized and exported.

Because the AHS data did not cover the entire extent of the RWB, we estimated the area of cropped wetlands based on its area in the surveyed AHS region. Therefore, we calculated the area of cultivated wetlands (i.e., Agriculture and Cropped Wetland map classes) both in the surveyed AHS region and the entire RWB. We then divided the cropped wetland area by the surveyed AHS region cultivated wetland area. The resulting percentage was multiplied by the cultivated wetland area in the entire RWB, which gave us an estimate of the cropped wetland area in the entire RWB.

The total acres of each habitat type in the RWB were multiplied by the energetic production estimates (kcal/ac) to describe the habitat types' potential energetic resources for waterfowl. According to Bishop and Vrtiska (2008), early successional habitats provide 250,000 kcal/ac, late successional habitats contain 25,000 kcal/ac, and cropped wetland habitats produce 100,000 kcal/ac. Kilocalorie production estimates were based on the seed production of the habitat types (101,215, 10,122, and 40,486 g/ac for early successional, late successional and cropped wetland, respectively) and the energy provided by a gram of seeds (i.e., true metabolizable energy) estimated at 2.47 kcal/ac (Bishop and Vrtiska 2008). Other estimates of energetic and seed production exist (Drahota 2012, Hagy and Kaminski 2012, Olmstead et al. 2013), but we used the aforementioned values to remain consistent with previous research and the RWBJV Waterfowl Plan (RWBJV 2013*d*).

<u>*Annual Accessible Forage Resources for Waterfowl*</u>

Estimates of total potential kilocalorie production are not reflective of the amount of actual forage resources accessible because they do not take into account the areas that were ponded (i.e., accessible foraging habitat). We combined the AHS ponding data and the 2004 and 2012 vegetation maps to evaluate accessible forage resources across the landscape under varying habitat conditions (i.e., vegetation communities present in 2004 and 2012) and different weather patterns (i.e., precipitation that resulted in the ponded habitat mapped in each AHS).

To combine the AHS survey data and vegetation maps, we first selected all of the polygons containing water from the individual years of AHS data. The water polygons from each AHS year were intersected with both the 2004 and 2012 vegetation maps. In each resulting shapefile, a field was added to describe the habitat type of ponded areas. The map classes used to describe annual forage resources were slightly different than those used to calculate total potential forage resources because the AHS inventoried all ponded hydric soils and the ponded area sometimes extended beyond the often ponded regions and onto the adjacent portion of the hydric soil that had been classified as upland habitat (i.e., Agriculture, Grass, and Woody Species map classes). Ponding of the upland habitats often occurs during periods of above average precipitation or in geographies that have intense precipitation events (i.e., >7 cm in <24 hr). Upland habitats were not included in the total potential forage production because those areas seldom pond water; however, when calculating the annual forage accessibility using AHS, ponded upland habitats could be identified. To account for the potential to flood upland areas, we assigned the Agriculture map class as cropped wetland habitat and the Grass map class as late successional habitat. The Woody Species map class remained upland habitat because, even if ponded, it does not provide suitable foraging habitat for most waterfowl species. The remaining map classes were assigned their previous habitat type of early successional, late successional, or cropped wetland. In ArcMap 10, we added a field in which area, in acres, was calculated for each polygon. Total ponded acres by habitat type were summarized and exported as a dBASE table. This process was repeated using each AHS year's data in conjunction with both the 2004 and 2012 vegetation maps.

We uploaded the dBASE tables and created pivot tables to summarize the acres of ponded water in cropped wetland, early successional, and late successional habitats in Microsoft Excel 2007. The habitat types' kilocalorie/acre productions were based on estimates by Bishop and Vrtiska (2008) as described previously. The estimated kilocalorie accessibility for waterfowl in the RWB by each habitat type for each AHS year was calculated using the following equations:

$$\%SamplePondWater = AreaPond / AreaSample;$$

$$AreaPondRWB = \%SamplePondWater \times AreaRWB;$$

and

$$Energy = AreaPondRWB \times EnergyPerArea$$

where:

%SamplePondWater = % of the sampled area that is ponding water for the habitat type,
AreaPond = Sampled area (ac) of ponded water for the habitat type,
AreaSample = Total area (ac) sampled for the habitat type,
AreaPondRWB = Estimated area (ac) of ponded water in the RWB for the habitat type,
AreaRWB = Total RWB wetland area (ac) for the habitat type,
Energy = Estimated energy (kcal) accessible in the habitat type,
EnergyPerArea = Energy per area (kcal/ac) produced by the habitat type.

We summed the accessible kilocalories of the three habitat types for the AHS year to calculate the accessible forage resources for each year of AHS using both the 2004 and 2012 vegetation maps. The average accessible kilocalories for waterfowl based on the 2004 and 2012 vegetation maps was calculated as the mean of all AHS years' accessible kilocalories using the respective vegetation map. Once the information was summarized, we compared kilocalorie accessibility between assessment years in early successional, late successional, cropped wetlands, and all habitats combined using paired *t*-tests in MINITAB version 16.1 (Minitab, Inc., State College, Pennsylvania). We tested assumptions of normal distribution and equal variances using an Anderson-Darling test and *F*-test, respectively (Helsel and Hirsch 2002, Minitab Inc. 2010). Alpha was set to 0.05 for all tests.

Mean Accessible Forage Resources for Waterfowl by Conservation Lands

To calculate the mean kilocalorie accessibility on the long-term conservation lands, we incorporated a vector-based Proportion Years Ponding Shapefile, derived from the Proportion Years Ponding Raster, as well as the 2004 and 2012 vegetation maps. We performed an intersect overlay to combine the 2004 or 2012 vegetation map, Proportion Years Ponding Shapefile, and long-term conservation lands boundaries. In the 2004 and 2012 intersected shapefiles, we added fields that we populated with the area in acres and the kilocalorie/acre for each habitat type. We included the Agriculture and Grass map classes in the cropped wetland and late successional habitats, respectively, because, as with the annual accessibility, we knew when these upland areas were ponded. We then added a field of the average kilocalorie accessibility per polygon on long-term conservation lands by multiplying the area in acres, the kilocalorie rate, and the proportion of years ponded. The attribute tables were uploaded in Microsoft Excel 2007 and pivot tables were created to determine the accessible kilocalories by the habitat types for each property type. An assumption we made in the calculation of the average kilocalorie accessibility on conservation lands was that wetlands restored between 2004 and 2012 were ponding water in similar areas before and after restoration.

Kilocalorie Accessibility for Shorebirds between Vegetation Assessment Years

Calculation of accessible kilocalories for shorebirds was based on the procedure set forth in the RWBJV Shorebird Plan and incorporates energetic rate and accessible habitat for each shorebird foraging guild (RWBJV 2013*b*). The different shorebird foraging guilds that use RWB wetlands include small-bodied probers/gleaners (e.g., Baird's Sandpiper [*Calidris bairdii*]), large-bodied probers (e.g., Lesser Yellowlegs [*Tringa flavipes*]), and swimmers (e.g., Wilson's Phalarope [*Phalaropus tricolor*]; Table A.2). Because each guild has different habitat needs, kilocalorie accessibility was calculated for each guild separately.

The energetic rate was the same for all guilds and was derived from the energy content of one gram of chironomids (*Chironomidae* family), assimilation efficiency, invertebrate availability, and foraging efficiency. Early successional, late successional, and cropped wetland habitat types were assumed to provide 10,238 kcal/ac because shorebirds mainly feed on invertebrates, which were assumed to be less influenced by vegetation type (RWBJV 2013*b*). The proportion of each habitat type that is expected to provide accessible foraging habitat for each guild was based on AHS ponding data, habitat surveys of Central Table Playas, and expert opinion of shorebird biologists and habitat managers (Table 2; RWBJV 2013*b*).

We determined the total area of early successional and late successional habitat types based on the area of associated map classes described in each of the vegetation maps. Because ponded area was not used in analysis, the Agriculture and Grass map classes were considered upland habitat. The area of cropped habitat was set to the same cropped wetland area used to determine the total potential kilocalorie production for waterfowl (i.e., extrapolated to the entire RWB area). We calculated each habitat type's accessible kilocalories for each shorebird guild by multiplying the total habitat area, the proportion of the habitat accessible to the shorebird guild, and 10,238 kcal/ac. The three habitats' accessible kilocalories were summed for each guild to determine the forage accessibility for the respective shorebird guild in 2004 and 2012. The kilocalorie accessibility per long-term conservation property type was calculated using the same method but based on the area of each habitat type within the respective property type.

Table 2. Percentage of wetland habitat types accessible for shorebird foraging guilds in the Rainwater Basin, Nebraska (RWBJV 2013*b*).

	Small-bodied Probers/Gleaners	Large-bodied Probers	Swimmers
Early Successional	5.0	10.0	10.0
Late Successional	0.0	1.5	1.5
Cropped Wetland	12.5	25.0	50.0

RESULTS AND DISCUSSION

Field Point Surveys

On WRP sites, 2,698 points were surveyed, of which 94% were on long-term WRPs. Of the 37 possible, predetermined cover types on long-term WRP sites, reed canarygrass, annual smartweed, other annual desirable species, and ragweed were common (i.e., recorded at >25.0% of points; Table A.4). We also surveyed 248 points on other long-term private conservation easements, at which annual smartweeds, reed canarygrass, and bare soil were common. On WMA properties, 2,827 points were surveyed, where ragweed, perennial smartweed (*Polygonum amphibium*), and annual smartweed were all observed at >25% of the points. WPA sites contained the most survey points (n = 6,821). Only two cover types were common on WPA sites: perennial smartweed and reed canarygrass.

When all sites were combined, a total of 12,594 points were surveyed, of which 12,424 were on long-term conservation lands and 170 were on short-term WRPs. The remaining 138 points planned for analysis were removed either because they were cropped or missed during surveys. A total of 35 cover types were observed on all sites combined; leafy spurge and purple loosestrife were not recorded. Although purple loosestrife and leafy spurge were present in the state, neither was common on RWB wetlands, with purple loosestrife occurring mainly on riverine wetlands and leafy spurge commonly observed on drier areas in northern Nebraska (Masters and Kappler 2002, Knezevic 2003). The mean number of cover types recorded per point was 2.8, with a range of one to eight types recorded per point. On long-term conservation lands overall, reed canarygrass was the most common, followed by perennial smartweed, ragweed, and annual smartweed. The frequency of reed canarygrass on conservation lands can be explained by its ability to outcompete other species and its ubiquitous presence in the region due to widespread seeding (Stubbendieck et al. 1995). Smartweeds and ragweeds were common species occurring in wetlands managed for moist-soil species.

Noxious weeds were considered those plant species extremely capable of outcompeting crops and native species and potentially poisonous or injurious to people, livestock, or wildlife. These species are of particular concern because, by law, landowners are obligated to control noxious weeds on any property in Nebraska (Noxious Weeds Control Act 2-945.01-2-966). Of the noxious weeds listed by the Nebraska Department of Agriculture, phragmites was recorded at nine points overall: three WRP points, each on a separate site, and six WPA points on one site. Musk thistle (*Carduus nutans*) was recorded at seven WRP points on two properties, two WMA points on two properties, and seven WPA points on four properties. Canada thistle was recorded at 60 points across six WPA sites and five points across three WMA properties. No noxious weeds were recorded on other long-term private conservation properties. Although NGPC, USFWS, and private landowners actively control noxious weeds on their properties, these species readily spread and are difficult to eradicate. These data illustrate that landowners and managers are successfully containing these species to relatively low numbers; however, they also demonstrate the difficulty of eradicating these undesirable species and the need for management practices to continue in order to control them.

Of the nine natural vegetation map classes (e.g., Moist-Soil Species), survey points on all sites combined contained a mean of 2.1 map classes (range = 1–5). Moist-Soil Species, which included 14 of the survey cover types (Table A.3), was the most common class recorded for each property type, being present at 77.2% of all points (Table 3). The prevalence of moist-soil species was due to a combination of land managers working to promote these species due to their high seed production for waterfowl and the Moist-Soil Species map class containing the most cover types of any map class. Water was the least common class on WRP sites, while Woody Species was the least common on all other property types. The rarity of Water and Woody Species can be explained by the 2012 drought conditions and management to remove trees, respectively.

Of the invasive species map classes, Reed Canarygrass was the most common, recorded at more than 25% of points and was the dominant vegetation at 12.0% of points (Table 4). River Bulrush and Cattail were observed less frequently, at 11.0% and 5.9% of points, respectively, and dominant at 3.8% and 2.8%, respectively. Reed canarygrass was more common due to it being seeded in the region and its ability to grow in a variety of moist conditions. Cattails and river bulrush are less common because they are more confined to the deepest (semi-permanent) wetland zone, which limits their spread. However, all of these species have the ability to outcompete native plants.

Table 3. Number and percentage of survey points that contained each vegetation map class for long-term Wetlands Reserve Program sites (WRP; *n* = 2,528), other long-term private easements (Other; *n* = 248), Wildlife Management Areas (WMA; *n* = 2,827), Waterfowl Production Areas (WPA; *n* = 6,821), and all sites combined (*n* = 12,424) in the Rainwater Basin region of Nebraska. Data from vegetation surveys conducted at sites in 2012.

	WRP		Other		WMA		WPA		All	
	#	%	#	%	#	%	#	%	#	%
Moist-Soil Species	2035	80.5	185	74.6	2428	85.9	4938	72.4	9586	77.2
Wet Meadow Species	616	24.4	19	7.7	486	17.2	1653	24.2	2774	22.3
Bare Soil/Mudflat	442	17.5	85	34.3	707	25.0	1703	25.0	2937	23.6
Water	16	0.6	20	8.1	116	4.1	152	2.2	304	2.4
Cattail	123	4.9	18	7.3	146	5.2	440	6.5	727	5.9
Reed Canarygrass	718	28.4	77	31.0	683	24.2	1904	27.9	3382	27.2
River Bulrush	243	9.6	20	8.1	278	9.8	828	12.1	1369	11.0
Grass	1042	41.2	37	14.9	1022	36.2	2638	38.7	4739	38.1
Woody Species	38	1.5	1	0.4	28	1.0	130	1.9	197	1.6

Table 4. Number and percentage of survey points dominated by each vegetation map class for long-term Wetlands Reserve Program sites (WRP; *n* = 2,528), other long-term private easements (Other; *n* = 248), Wildlife Management Areas (WMA; *n* = 2,827), Waterfowl Production Areas (WPA; *n* = 6,821), and all sites combined (*n* = 12,424) in the Rainwater Basin region of Nebraska. Data from vegetation surveys conducted at sites in 2012.

	WRP		Other		WMA		WPA		All	
	#	%	#	%	#	%	#	%	#	%
Moist-Soil Species	1095	43.3	106	42.7	1236	43.7	2083	30.5	4520	36.4
Wet Meadow Species	231	9.1	5	2.0	142	5.0	587	8.6	965	7.8
Bare Soil/Mudflat	198	7.8	34	13.7	251	8.9	659	9.7	1142	9.2
Water	5	0.2	4	1.6	63	2.2	93	1.4	165	1.3
Cattail	44	1.7	3	1.2	68	2.4	229	3.4	344	2.8
Reed Canarygrass	333	13.2	38	15.3	336	11.9	790	11.6	1497	12.0
River Bulrush	71	2.8	10	4.0	71	2.5	316	4.6	468	3.8
Grass	393	15.5	25	10.1	419	14.8	1363	20.0	2200	17.7
Woody Species	13	0.5	0	0.0	8	0.3	47	0.7	68	0.5
Tie of ≥2 Classes	145	5.7	23	9.3	233	8.2	654	9.6	1055	8.5

Vegetation Map Polygons

A total of 6,961 undissolved polygons were surveyed, with the final undissolved vegetation map containing 134,265 individual polygons covering 79,575 ha (Figure 5). The dissolved vegetation map contained 45,777 polygons (Figure 6). Long-term WRP sites contained 1,545 ha of wetlands, other long-term private easements 226 ha, WMA properties 2,316 ha, and WPA properties 5,480 ha.

Of the surveyed polygons, 3,424 were used as training data and 2,459 were used as testing data. The remaining 1,078 surveyed polygons were used for neither testing nor training data because each polygon's most common map class did not cover >50% of the polygon's surveyed area, which was a requirement of training and testing data. Surveyed polygons covered 58.2% of surveyed properties, 32.6% of all the natural vegetation, and 7.7% of the entire vegetation map. The most common map class in surveyed polygons was Moist-Soil Species, followed distantly by Grass and Reed Canarygrass (Table 5). The least common class in surveyed WRP polygons was Water and in all other property types was Woody Species.

In the entire vegetation map, the Agriculture map class covered over 75% of the historical wetland area (Table 6). Moist-Soil Species was the most common class among natural vegetation types, which was not surprising since habitat managers are actively managing for this community and privately-owned wetlands are often integrated into local farm operations for grazing and haying that promote early successional species. Water was the least common map class, likely due to the drought conditions in 2012 and ephemeral nature of playa wetlands. Irrigation reuse pits covered 496 ha of the vegetation map. Of the natural vegetation, 925 ha were known to be disked in 2012 by DU, USFWS, and NGPC.

The percentage of each map class's area was relatively similar between the surveyed polygons and the entire vegetation map. However, the amount of Bare Soil/Mudflat was lower in the entire map, likely due to management activities on surveyed properties, such as disking and supplemental water deliveries (i.e., surface water deliveries or groundwater pumping). The entire vegetation map also had slightly more Grass, Reed Canarygrass, and Woody Species than surveyed properties, which was likely due to management activities on surveyed properties disturbing the vegetation community and preventing succession to grasses, reed canarygrass, and trees, which are late successional communities.

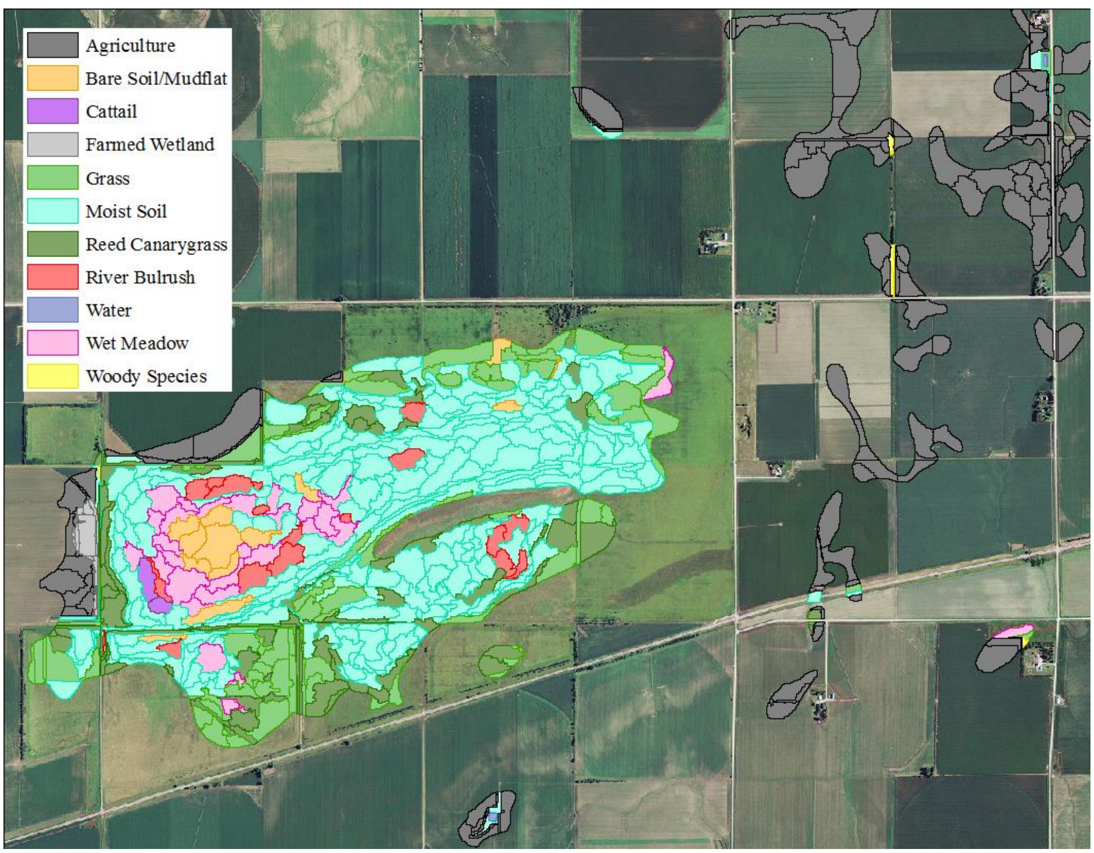

Figure 5. Wetlands in Clay County, Nebraska, representing a portion of the final, undissolved

2012 vegetation map, including 2012 mid-summer aerial imagery, of the Rainwater Basin.

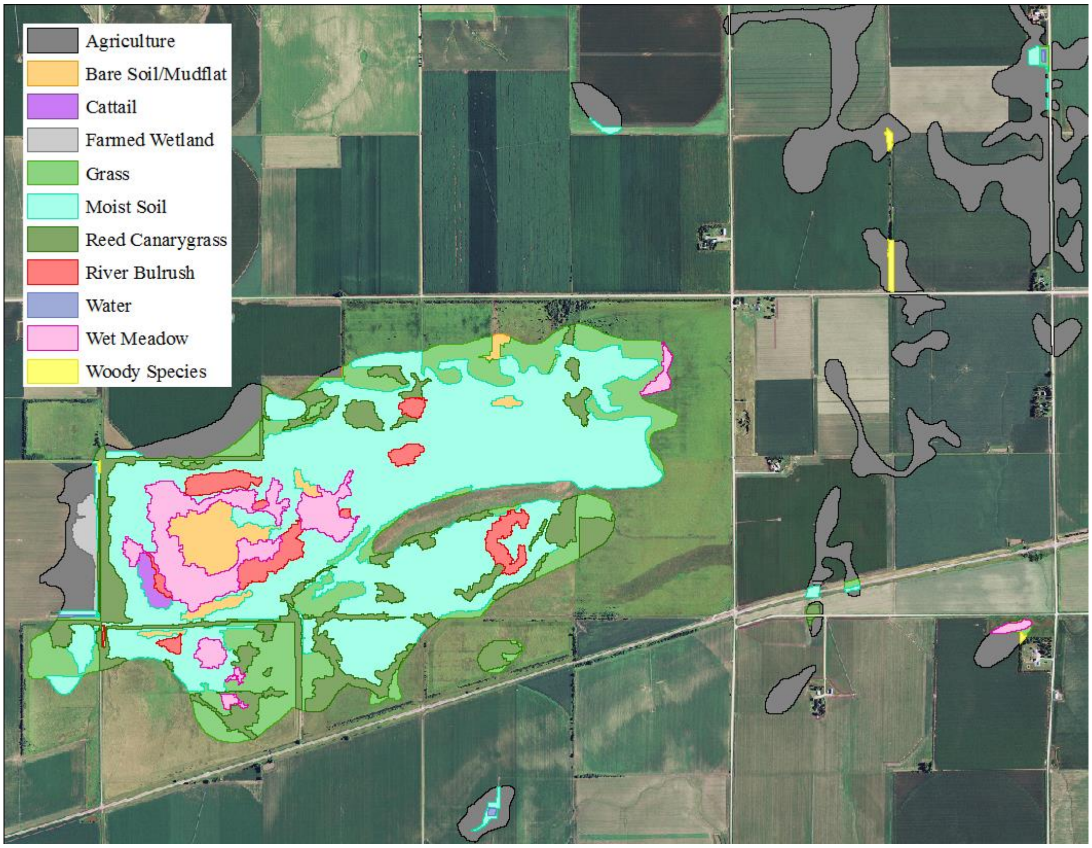

Figure 6. Wetlands in Clay County, Nebraska, representing a portion of the final, dissolved 2012 vegetation map, including 2012 mid-summer aerial imagery, of the Rainwater Basin.

Table 5. Area (ha) of surveyed polygons dominated by each vegetation map class and the percentage of the property type's surveyed area covered by each class for long-term Wetlands Reserve Program sites (WRP; *n* = 1,755), other long-term private easements (Other; *n* = 162), Wildlife Management Areas (WMA; *n* = 1,549), Waterfowl Production Areas (WPA; *n* = 3,522), and all sites combined (*n* = 6,988) in the Rainwater Basin region of Nebraska. Data from vegetation surveys conducted at sites in 2012.

	WRP		Other		WMA		WPA		All	
	ha	%	ha	%	ha	%	ha	%	ha	%
Moist-Soil Species	507.4	46.0	40.5	42.7	574.4	46.0	1070.5	33.9	2192.8	39.1
Wet Meadow Spp.	119.2	10.8	2.8	3.0	71.1	5.7	286.5	9.1	479.7	8.6
Bare Soil/Mudflat	68.5	6.2	13.1	13.8	131.1	10.5	248.6	7.9	461.3	8.2
Water	0.9	0.1	3.3	3.5	30.6	2.5	57.3	1.8	92.0	1.6
Cattail	19.1	1.7	1.3	1.4	29.8	2.4	86.5	2.7	136.8	2.4
Reed Canarygrass	137.8	12.5	15.2	16.0	145.7	11.7	347.8	11.0	646.5	11.5
River Bulrush	24.7	2.2	1.5	1.6	30.6	2.4	207.3	6.6	264.0	4.7
Grass	183.4	16.6	10.6	11.2	158.4	12.7	679.8	21.5	1032.2	18.4
Woody Species	3.6	0.3	0.0	0.0	3.1	0.2	12.5	0.4	19.2	0.3
Tie of ≥2 Classes	38.5	3.5	6.4	6.8	72.8	5.8	159.9	5.1	277.6	5.0

Table 6. Area of each map class in the final vegetation map of wetlands in the Rainwater Basin, Nebraska. Also included are the percentage of the area of the entire map each map class covers and percentage of the area of natural vegetation (i.e., not Agriculture or Cropped Wetland) each of the non-cultivated classes covers.

Class	Area (ha)	% of Entire Map	% of Natural Vegetation
Moist-Soil Species	7,059.1	8.9	39.5
Wet Meadow Species	1,305.5	1.6	7.3
Bare Soil/Mudflat	686.8	0.9	3.8
Water	468.5	0.6	2.6
Cattail	488.9	0.6	2.7
Reed Canarygrass	2,650.5	3.3	14.8
River Bulrush	678.5	0.9	3.8
Grass	3,974.2	5.0	22.2
Woody Species	575.9	0.7	3.2
Cropped Wetland	709.8	0.9	---
Agriculture	60,977.3	76.6	---

Accuracy Assessment

The accuracy assessment indicated 62.9% accuracy on non-surveyed natural vegetation polygons. When combined with the 100% accuracy of surveyed polygons, we had 84.5% natural vegetation accuracy on surveyed properties, 62.9% natural vegetation accuracy on non-surveyed properties, and 75.0% natural vegetation accuracy for the overall map. The accuracy of the Agriculture and Cropped Wetland map classes was not assessed. However, the Agriculture and Cropped Wetland map classes have a distinct, homogeneous spectral signature, so their accuracies are likely close to 100%. For the 2004 vegetation map, the producer accuracy of the Agriculture map class was 99.9% and the user accuracy was 99.2% (Bishop and Vrtiska 2008); thus, we assume the 2012 vegetation map had similar accuracies.

The producer accuracy was highest for Reed Canarygrass and lowest for Bare Soil/Mudflat (Table 7). Bare Soil/Mudflat was easily distinguishable when it was very dominant (i.e., >75% dominant), but was difficult when it was only slightly dominant (i.e., near 50% dominant). User accuracy was highest in Water and Woody Species because they were easily classified correctly when they were very dominant. River Bulrush and Reed Canarygrass had the lowest user accuracies. The higher producer but lower user accuracy of Reed Canarygrass was because the majority, but not all, of polygons that appeared as white in spring infrared imagery were Reed Canarygrass. Because the majority was Reed Canarygrass, we classified most of the white polygons as such, causing higher producer accuracy because we correctly classified much of the actual Reed Canarygrass, but lower user accuracy because we included extra polygons classified as Reed Canarygrass.

Table 7. The error matrix and producer and user accuracies for each surveyed map class in a wetland vegetation map in the Rainwater Basin, Nebraska, 2012. Producer accuracies represent the probability a testing area was correctly classified. User accuracies represent the probability classification correctly denoted field conditions. Shaded cells are the area (ha) of each class that is classified correctly. Testing data were based on field vegetation surveys conducted in 2012.

		Testing Data Classification (ha)										Accuracy (%)	
		Moist-S.	W. Mead.	B. Soil/Mud.	Water	Cattail	R. Canary.	Riv. Bul.	Grass	Woody	Total	Producer	User
Vegetation Map Classification (ha)	Moist-Soil	599.4	70.0	52.9	1.8	12.0	13.6	65.1	74.4	13.2	902.5	73.0	66.4
	Wet Meadow	45.1	103.1	2.4	0.0	0.0	1.9	11.6	21.5	0.3	185.9	45.6	55.5
	Bare Soil/Mudflat	21.3	1.8	43.0	0.0	0.7	1.0	0.9	5.0	2.5	76.2	31.8	56.4
	Water	0.2	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	1.9	40.7	91.8
	Cattail	12.6	0.6	4.4	0.0	32.8	3.7	0.3	0.0	4.9	59.4	58.8	55.2
	Reed Canarygrass	38.0	3.7	5.6	0.3	7.5	74.1	1.0	1.9	3.1	135.1	76.4	54.8
	River Bulrush	54.1	13.6	6.1	0.0	2.8	1.8	132.0	33.8	0.0	244.2	57.4	54.1
	Grass	49.4	33.1	19.6	0.4	0.0	0.5	19.4	257.3	0.0	379.7	65.3	67.8
	Woody Species	0.5	0.0	1.2	0.0	0.0	0.3	0.0	0.0	18.5	20.5	43.5	90.2
	Total	820.6	225.9	135.1	4.3	55.8	97.0	230.2	394.0	42.5	2005.3		

Comparison of Habitat between 2004 and 2012 Vegetation Maps

The total area of wetlands on long-term conservation lands increased 982.5 ha between 2004 and 2012 (Table 8), mainly due to additional enrollment in WRP and other long-term conservation easements developed by DU. Although the analysis showed a decrease in total potential wetland area (312.7 ha), the decrease was due to different methods when creating the vegetation maps and not actual wetland loss. For the 2012 vegetation map, polygons covering large developed areas (e.g., residential areas) were deleted and therefore not considered a wetland, while for the 2004 vegetation map, those polygons were left in the map and assigned as Agriculture.

Comparison of conservation lands between 2004 and 2012 showed that desirable Moist-Soil Species increased substantially (>10%) on WRP and WMA properties (Table 8). On WPA sites, however, the percentage of Moist-Soil Species decreased. Reed Canarygrass, a major problem species, slightly increased on WRP sites and slightly decreased on WMA and WPA properties (Table 8), indicating that management activities on public properties are helping to prevent further spread of reed canarygrass. Another significant change between 2004 and 2012 was the percentage of wetlands classified as Agriculture and Cropped Wetland greatly decreased in WRP properties (Table 8), which was due to recent easement acquisitions in the program in 2004 that had not yet been restored. By 2012, the easements were largely restored. Because only a single property with 0.03 ha of wetland was in the other long-term private easement category in 2004, percentage changes between 2004 and 2012 should not be used to assess changes in map classes for this property type.

Of the 11,690 wetland footprints mapped in 2004, a total of 1,730 contained >0.2 ha of hydrophytic communities, of which 878 did not contain an irrigation reuse pit. The majority (56%) of the 1,730 footprints contained <25% hydrophytic communities by area (Table 9). In the 2012 vegetation map, 11,700 wetland footprints were mapped, of which 1,952 contained >0.2 ha of hydrophytic communities and 1,130 had hydrophytic communities but did not contain an irrigation reuse pit. A total of 62% of the wetland footprints with >0.2 ha of hydrophytic communities contained <25%, by area, of hydrophytic communities in 2012. The increase in wetland footprints containing >0.2 ha of hydrophytic communities was partially due to wetland restorations on long-term conservation lands, which was responsible for 26 footprints being converted from <0.2 ha to >0.2 ha of hydrophytic communities. Also, 630 footprints contained >0.2 ha of cropped wetlands in 2004. In 2012, the number of footprints with >0.2 ha of cropped habitat decreased to 561. These data show that restoration efforts are increasing the area of hydrophytes in partially restored wetlands as well as previously unrestored wetlands, which provide habitat across additional areas of the landscape.

A total of 1,430 and 1,438 footprints contained at least one pit in 2004 and 2012, respectively, while 578 and 616 footprints contained at least one pit but no hydrophytic communities in the respective years. However, the number of footprints containing pits cannot be directly compared between 2004 and 2012 because the shapefile outlining irrigation reuse pits was redone to more thoroughly map pits in 2010. Thus, more potential pits were included in the 2012 vegetation map than the 2004 map.

The cropped wetland areas recorded in the 2004 and 2012 vegetation maps were 927.0 ha and 691.0 ha, respectively. When extrapolated to estimate area of cropped wetlands in the entire RWB, an estimated 971.6 ha of cropped wetlands existed in 2004 and 724.5 ha in 2012. The decrease in area of cropped wetlands from 2004 to 2012 was partially due to cropped wetlands being enrolled in conservation programs and converted to early and late successional habitats. We note that the area of cropped wetland habitat was calculated based on spring ponding data to quantify spring migration habitat, and does not necessarily reflect the larger extent of ponded cropland later in the year, which would be influenced by more intense late-spring precipitation and irrigation runoff. The area of Stressed Agriculture mapped in 2004 was 3,357 ha, revealing that simply basing the area of cropped wetlands on stressed agriculture spectral signatures in one year of imagery can greatly overestimate the area of spring ponding. These data highlight the importance of mapping inundation patterns from multiple years when estimating long-term inundation probability of individual sites.

Table 8. The change in vegetation map classes between the 2004 and 2012 vegetation maps for long-term Wetlands Reserve Program sites (WRP), other long-term private easements (Other), Wildlife Management Areas (WMA), Waterfowl Production Areas (WPA), and the entire vegetation map in the Rainwater Basin, Nebraska, including the change in total area (ha) of each class and change in the wetland area percentage for each class. Percentages calculated from wetland area in easements for the respective years. A positive number indicates a net increase from 2004 to 2012, and a negative number indicates a net decrease.

	WRP		Other		WMA		WPA		Entire Map	
	ha	%	ha	%	ha	%	ha	%	ha	%
Moist-Soil Spp.	428.1	15.5	95.0	12.6	260.2	10.6	-270.0	-5.9	477.4	0.6
Wet Mead. Spp.	35.4	-2.7	9.5	4.2	-11.1	-0.6	230.5	4.1	204.1	0.3
Water/Bare Soil	-22.4	-5.3	16.3	7.2	69.5	2.9	271.9	4.9	-121.5	-0.1
Cattail	14.9	0.5	6.8	3.0	-26.3	-1.2	-17.3	-0.4	45.3	0.1
R. Canarygrass	115.2	3.8	40.7	-52.7	-76.0	-3.5	-111.7	-2.3	16.4	0.0
River Bulrush	0.1	-1.4	6.6	2.9	-86.9	-3.9	-141.0	-2.8	-927.1	-1.2
Grass	202.8	10.5	39.4	17.4	-81.3	-3.8	188.7	2.9	1279.1	1.6
Woody Species	8.1	0.5	0.7	0.3	25.6	1.1	-5.8	-0.1	470.7	0.6
Crop. Wetland	-52.7	-5.6	1.4	0.6	-4.1	-0.2	1.3	0.0	-236.0	-0.3
Agriculture	-141.0	-15.4	7.5	3.3	-31.3	-1.4	-17.5	-0.3	-1479.5	-1.6
Pit	2.6	-0.3	2.3	1.0	-1.5	-0.1	-0.4	0.0	-41.5	0.0
Total	591.0	---	226.2	---	36.7	---	128.6	---	-312.7	---

Table 9. Comparison between the 2004 and 2012 vegetation maps of the number of historical wetland footprints that contain >0–25%, >25–50%, >50–75%, and >75% hydrophytic communities (i.e., Bare Soil/Mudflat, Cattail, Moist-Soil Species, Reed Canarygrass, River Bulrush, Water, and Wet Meadow Species, excluding irrigation reuse pits) in the Rainwater Basin, Nebraska. Wetland footprints had to contain over 0.2 ha of hydrophytic communities to be included. A positive difference indicates a net increase from 2004 to 2012, while a negative difference indicates a net decrease between 2004 and 2012.

	2004	2012	Difference
>0–25%	972	1214	242
>25–50%	282	314	32
>50–75%	221	239	18
>75%	254	184	-70

Kilocalorie Accessibility for Waterfowl between Vegetation Assessment Years

Total Potential Forage Production for Waterfowl

Based on the 2012 vegetation map, the total potential forage production for waterfowl in RWB wetlands was 6.1 billion kcal. Of those, 5.7 billion kcal would be produced by early successional habitats, 0.26 billion kcal by late successional habitats, and 0.18 billion kcal by cropped wetland habitats. The total potential kilocalorie production for waterfowl based on the 2004 vegetation map was 5.9 billion kcal, 0.23 billion kcal lower than the estimate based on the 2012 map. The increase in total potential forage since 2004 was due to late successional and cropped wetland habitats being converted to early successional.

When comparing the 2012 total potential production to the previous estimate presented in Bishop and Vrtiska (2008) that used the 2004 vegetation map, potential production by early and late successional habitat types was similar (5.5 billion kcal and 0.26 billion kcal in 2004, respectively). However, the 2012 potential production by cropped wetlands was much lower than the previous estimate (0.79 billion kcal). Estimates in Bishop and Vrtiska (2008) were based on areas appearing as stressed agriculture in the 2004 vegetation map, giving a higher estimate of cropped wetland habitat compared to the hierarchical estimate developed using the AHS.

Accessible Forage Resources for Waterfowl – Regionwide and Conservation Lands

Although RWB wetlands had the potential to produce 6.1 billion kcal, the actual accessible forage resources were much lower as not all wetlands were ponded. When the 2012 vegetation map was assessed in conjunction with the AHS data, RWB wetlands contained a mean of 3,269 ha of ponded water and 1.3 billion kcal, only 21% of the total potential forage (Table 10). Of those, the long-term conservation lands supplied an average of 0.77 billion kcal, more than 50% of the average accessible kilocalories on RWB wetlands (Table 11).

The range of kilocalories supplied by RWB wetlands each year was large, from 0.43 billion kcal in 2006 to 2.7 billion kcal in 2010, reflecting the high degree of inter-annual variation in inundation of RWB wetlands (Table 12). The RWBJV Waterfowl Plan indicates a need for 4.4 billion kcal from RWB wetland seeds during spring migration to allow the target population of waterfowl (8.6 million individuals) to remain healthy (RWBJV 2013*d*). Based on our 2012 estimates, RWB wetlands were capable of supplying more than the required energy if all wetland areas ponded water. However, the current accessible forage resources were still lacking 3.1 billion kcal on average and 1.7 billion kcal in the wettest year analyzed (i.e., 2010).

Our analyses highlighted the importance of early successional habitats for kilocalorie accessibility. Based on the integration of AHS ponding data into the 2012 vegetation map, early successional habitats provided between 80% of the annual accessible kilocalories in 2004 and 93% in 2011, while cropped wetland habitats supplied from 3% in 2011 and 2012 to 15% in 2007 (Table 12). The proportion of kilocalories supplied by late successional habitats was more consistent, ranging from 4% in 2009 and 2010 to 6% in 2004 and 2006 (Table 12). The proportions of kilocalorie accessibility from early successional and cropped wetland habitats were inversely related, with the highest proportions of early successional forage accessibility in the four years with the least ponding water and the highest proportions of cropped wetland forage accessibility in the four years with the most ponding. The areas that pond water first are more likely than other areas to pond in drier years and contain early successional species or some late successional species (e.g., cattails and river bulrush). However, certain late successional species (e.g., reed canarygrass) and cropped wetland habitats, which are generally hydrologically modified, occur in drier areas that usually flood only in wetter years. Also, land managers are more apt to add supplemental water to wetlands dominated by early successional habitats to maximize accessible forage resources. These phenomena cause greater proportions of early successional accessible kilocalories in drier years and greater proportions of cropped wetland accessible kilocalories in wetter years. Although late successional habitats dominated by cattails and river bulrush are generally in the deep, semi-permanent zones that are more likely to pond water, they provide little forage production (four times less than cropped wetlands and ten times less than early successional); therefore, they do not have much impact on overall accessibility.

Between 2012 and 2004, kilocalorie accessibility increased. Mean kilocalorie accessibility based on AHS ponding data using the 2004 vegetation map was 1.2 billion kcal, and the average accessibility on long-term conservation lands was 0.63 billion kcal, 0.13 billion kcal lower for each of the respective values than described in the 2012 map (Table 13). Between 2004 and 2012, the kilocalorie accessibility on the long-term conservation lands increased slightly more (0.002 billion kcal) than the mean accessibility for the entire RWB because the gains on conservation lands were slightly offset by losses of forage accessibility on cropped and late successional habitats in the entire region.

Early successional habitats and all habitats combined in the 2012 map supplied significantly more (P <0.05) kilocalories than those in the 2004 map (Table 10). However, fewer (P <0.05) kilocalories were supplied in late successional and cropped wetland habitats (Table 10). These data indicate wetland restoration and management practices in the RWB are successfully supplying more kilocalories for waterfowl by shifting habitats from late successional and cropped wetland to early successional as well as providing restoration efforts in areas that successfully pond water.

Table 10. Comparison between the 2004 and 2012 vegetation maps of the mean kilocalorie accessibility for waterfowl in wetlands in the Rainwater Basin, Nebraska, by early successional, late successional, cropped wetland, and all habitats combined. A positive difference indicates a net increase in kilocalorie accessibility from 2004 to 2012, while a negative difference indicates a net decrease in accessibility between 2004 and 2012. An asterisk (*) indicates significance at P ≤0.05. N = 8.

	2004		2012		*t*-value	*P*-value
	$\bar{x}$	SE	$\bar{x}$	SE		
Early Successional	917,208,481	190,486,574	1,088,835,723	223,604,135	-3.71	0.008*
Late Successional	69,888,069	13,118,152	58,823,964	12,007,685	4.86	0.002*
Cropped Wetland	165,595,238	59,014,714	136,914,974	50,362,152	2.68	0.032*
Total	1,152,691,788	260,962,811	1,284,574,662	283,010,519	-3.88	0.006*

Table 11. Mean kilocalorie accessibility for waterfowl by early successional, late successional, cropped wetland, and all habitats combined on long-term Wetlands Reserve Program sites (WRP), other long-term private easements (Other), Wildlife Management Areas (WMA), Waterfowl Production Areas (WPA), and all sites combined in the Rainwater Basin, Nebraska. Values are based on the vegetation in the 2012 vegetation map and the ponded areas determined by the Annual Habitat Survey (2004, 2006–2012; Bishop et al., RWBJV, in review).

	WRP	Other	WMA	WPA	All
Early Successional	128,643,725	14,920,666	209,590,107	384,430,955	737,585,453
Late Successional	4,650,463	725,728	5,629,884	16,521,950	27,528,025
Cropped Wetland	171,737	159,218	35,639	115,192	481,786
Total	133,465,925	15,805,612	215,255,630	401,068,097	765,595,264

Table 12. Annual accessible kilocalories for waterfowl by early successional, late successional, cropped wetland, and all habitats combined in wetlands in the Rainwater Basin, Nebraska. Values are based on the vegetation in the 2012 vegetation map and the ponded areas determined by the Annual Habitat Survey (2004, 2006–2012; Bishop et al., RWBJV, in review).

Year	Early Successional	Late Successional	Cropped Wetland	Total
2004	1,157,106,934	79,395,921	205,604,449	1,442,107,304
2006	387,282,854	23,691,117	17,752,236	428,726,207
2007	1,659,114,784	95,646,266	303,883,983	2,058,645,033
2008	1,188,849,323	61,602,594	107,806,192	1,358,258,109
2009	1,146,747,064	52,931,680	51,852,826	1,251,531,569
2010	2,200,720,696	109,573,791	377,184,892	2,687,479,378
2011	489,966,852	24,107,088	15,375,571	529,449,510
2012	480,897,281	23,643,260	15,859,644	520,400,186

Table 13. Differences in mean kilocalorie accessibility for waterfowl between vegetation in the 2004 and 2012 vegetation maps by early successional, late successional, cropped wetland, and all habitats combined on long-term Wetlands Reserve Program sites (WRP), other long-term private easements (Other), Wildlife Management Areas (WMA), Waterfowl Production Areas (WPA), and all sites combined in the Rainwater Basin, Nebraska. Kilocalories calculated based on the area in easements for the respective years. A positive difference indicates a net increase in kilocalorie accessibility from 2004 to 2012, while a negative difference indicates a net decrease in accessibility between 2004 and 2012. Values are based on the vegetation in the 2004 and 2012 vegetation maps and the ponded areas determined by the Annual Habitat Survey (2004, 2006–2012; Bishop et al., RWBJV, in review).

	WRP	Other	WMA	WPA	All
Early Successional	51,262,469	14,919,210	48,794,608	31,840,231	146,816,518
Late Successional	1,935,915	725,297	-4,296,492	-3,212,371	-4,847,651
Cropped Wetland	-7,904,980	159,218	-709,972	11,559	-8,444,175
Total	45,293,405	15,803,724	43,788,144	28,639,419	133,524,692

Kilocalorie Accessibility for Shorebirds between Vegetation Assessment Years

The kilocalories accessible for shorebird use in 2012 ranged from 13.9–33.9 million kcal in the entire RWB and 6.9–14.6 million kcal on long-term conservation lands, depending on the shorebird foraging guild (Tables 14 and 15). The 2012 estimated accessible kilocalories were below the total kilocalories needed to support the target populations of small-bodied probers/gleaners (159,000 individuals) and large-bodied probers (121,000 individuals) by 25.8 million kcal and 35.9 million kcal, respectively (RWBJV 2013*b*). Our estimated accessible forage for swimmers was 3.4 million kcal above the energetic needs to support the target swimmer population (79,000 individuals; RWBJV 2013*b*).

The RWB forage accessibility for all shorebird guilds was greater in 2004 than in 2012 (Table 16). The changes were mainly due to the decrease in cropped habitat between 2004 and 2012. For all shorebird guilds, a larger portion of cropped wetland habitat was suitable than early successional habitat. Although early successional habitat area increased, the benefit was outweighed by the loss of cropped wetland habitat. Kilocalorie accessibility for shorebirds on long-term conservation lands was higher for all guilds in 2012 (Table 17). On long-term conservation lands, losses in cropped wetland habitats between 2004 and 2012 were outweighed by a combination of more total area in conservation programs and late successional habitats shifting to early successional.

Our 2004 and 2012 accessible kilocalorie estimates were far below the previous estimates in the RWBJV Shorebird Plan that uses the 2004 vegetation map (RWBJV 2013*b*). The lower estimates than the Shorebird Plan were due to a difference in analysis methods. We calculated the area of cropped wetlands based on AHS ponding data (972 ha in 2004 and 725 ha in 2012), while the Shorebird Plan determined cropped wetlands based the Stressed Agriculture map class defined in the 2004 vegetation map (4,834 ha; RWBJV 2013*b* p. 58). The different method for identifying cropped wetland habitat caused lower estimates of kilocalorie accessibility than predicted in the Shorebird Plan, which estimated forage accessibility at 26.0 million kcal for small-bodied probers/gleaners, 53.7 million kcal for large-bodied probers, and 84.3 million kcal for swimmers (RWBJV 2013*b*).

Table 14. Accessible kilocalories for shorebird foraging guilds (small-bodied prober/gleaner, large-bodied prober, swimmer) by early successional, late successional, cropped wetland, and all habitats combined in wetlands in the Rainwater Basin, Nebraska. Values are based on the vegetation in the 2012 vegetation map.

	Small-bodied Prober/Gleaner[a]	Large-bodied Prober[b]	Swimmer[c]
Early Successional	11,573,784	23,147,567	23,147,567
Late Successional	0	1,621,269	1,621,269
Cropped Wetland	2,291,242	4,582,484	9,164,967
Total	13,865,025	29,351,319	33,933,803

[a]E.g., Semipalmated Plover (*Charadrius semipalmatus*), Baird's Sandpiper (*Calidris bairdii*)
[b]E.g., Greater Yellowlegs (*Tringa melanoleuca*), Long-billed Dowitcher (*Limnodromus scolopaceus*)
[c]E.g., Wilson's Phalarope (*Phalaropus tricolor*)

Table 15. Accessible kilocalories for shorebird foraging guilds (small-bodied prober/gleaner, large-bodied prober, swimmer) by early successional, late successional, cropped wetland, and all habitats combined on long-term Wetlands Reserve Program sites (WRP), other long-term private easements (Other), Wildlife Management Areas (WMA), Waterfowl Production Areas (WPA), and all conservation lands combined in the Rainwater Basin, Nebraska. Values are based on the vegetation in the 2012 vegetation map.

	Small-bodied Prober/Gleaner[a]	Large-bodied Prober[b]	Swimmer[c]
WRP			
Early Successional	1,223,510	2,447,020	2,447,020
Late Successional	0	108,072	108,072
Cropped Wetland	2,722	5,444	10,889
Total	1,226,232	2,560,536	2,565,981
Other			
Early Successional	152,715	305,430	305,430
Late Successional	0	21,411	21,411
Cropped Wetland	4,491	8,983	17,966
Total	157,207	335,824	344,807
WMA			
Early Successional	1,909,064	3,818,128	3,818,128
Late Successional	0	158,788	158,788
Cropped Wetland	435	871	1,742
Total	1,909,499	3,977,786	3,978,657
WPA			
Early Successional	3,621,651	7,243,302	7,243,302
Late Successional	0	444,808	444,808
Cropped Wetland	4,562	9,124	18,248
Total	3,626,213	7,697,233	7,706,357
All Conservation Lands			
Early Successional	6,906,940	13,813,879	13,813,879
Late Successional	0	733,079	733,079
Cropped Wetland	12,211	24,422	48,844
Total	6,919,151	14,571,380	14,595,802

[a]E.g., Semipalmated Plover (*Charadrius semipalmatus*), Baird's Sandpiper (*Calidris bairdii*)
[b]E.g., Greater Yellowlegs (*Tringa melanoleuca*), Long-billed Dowitcher (*Limnodromus scolopaceus*)
[c]E.g., Wilson's Phalarope (*Phalaropus tricolor*)

Table 16. Differences in accessible kilocalories for shorebird foraging guilds (small-bodied prober/gleaner, large-bodied prober, swimmer) between vegetation in the 2004 and 2012 vegetation maps by early successional, late successional, cropped wetland, and all habitats combined in wetlands in the Rainwater Basin, Nebraska. A positive difference indicates a net increase in kilocalorie accessibility from 2004 to 2012, while a negative difference indicates a net decrease in accessibility between 2004 and 2012. Values are based on the vegetation in the 2004 and 2012 vegetation maps.

	Small-bodied Prober/Gleaner[a]	Large-bodied Prober[b]	Swimmer[c]
Early Successional	708,189	1,416,379	1,416,379
Late Successional	0	-343,780	-343,780
Cropped Wetland	-781,279	-1,562,557	-3,125,115
Total	-73,089	-489,959	-2,052,516

[a]E.g., Semipalmated Plover (*Charadrius semipalmatus*), Baird's Sandpiper (*Calidris bairdii*)
[b]E.g., Greater Yellowlegs (*Tringa melanoleuca*), Long-billed Dowitcher (*Limnodromus scolopaceus*)
[c]E.g., Wilson's Phalarope (*Phalaropus tricolor*)

Table 17. Differences in accessible kilocalories for shorebird foraging guilds (small-bodied prober/gleaner, large-bodied prober, swimmer) between vegetation in the 2004 and 2012 vegetation maps by early successional, late successional, cropped wetland, and all habitats combined on long-term Wetlands Reserve Program sites (WRP), other long-term private easements (Other), Wildlife Management Areas (WMA), Waterfowl Production Areas (WPA), and all conservation lands combined in wetlands in the Rainwater Basin, Nebraska. A positive difference indicates a net increase in kilocalorie accessibility from 2004 to 2012, while a negative difference indicates a net decrease in accessibility between 2004 and 2012. Values are based on the vegetation in the 2004 and 2012 vegetation maps.

	Small-bodied Prober/Gleaner[a]	Large-bodied Prober[b]	Swimmer[c]
WRP			
Early Successional	557,902	1,115,804	1,115,804
Late Successional	0	50,402	50,402
Cropped Wetland	-166,765	-333,531	-667,061
Total	391,137	832,676	499,145
Other			
Early Successional	152,704	305,409	305,409
Late Successional	0	21,403	21,403
Cropped Wetland	4,491	8,983	17,966
Total	157,196	335,795	344,778
WMA			
Early Successional	402,973	805,947	805,947
Late Successional	0	-72,360	-72,360
Cropped Wetland	-13,000	-25,999	-51,998
Total	389,974	707,588	681,589
WPA			
Early Successional	293,858	587,716	587,716
Late Successional	0	-102,639	-102,639
Cropped Wetland	4,075	8,150	16,300
Total	297,933	493,226	501,376
All Conservation Lands			
Early Successional	1,407,438	2,814,875	2,814,875
Late Successional	0	-103,193	-103,193
Cropped Wetland	-171,199	-342,397	-684,794
Total	1,236,239	2,369,285	2,026,888

[a]E.g., Semipalmated Plover (*Charadrius semipalmatus*), Baird's Sandpiper (*Calidris bairdii*)
[b]E.g., Greater Yellowlegs (*Tringa melanoleuca*), Long-billed Dowitcher (*Limnodromus scolopaceus*)
[c]E.g., Wilson's Phalarope (*Phalaropus tricolor*)

MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

WRP Management

Long-term WRP sites in the RWB provided 1,545 ha of wetland area in 2012. The increase in viable wetland area since 2004 provides additional habitat and forage for wildlife. More specifically, WRP wetlands provided stopover habitat; increased the kilocalorie accessibility for migratory wetland-dependent birds during migration; contributed 10.4% of the accessible kilocalories for waterfowl produced by RWB wetlands; and provided 7.6 – 8.8% of the accessible kilocalories for shorebirds, depending on the guild.

With 99% of the RWB privately owned, the RWBJV recognizes the importance of privately owned wetlands, including WRP sites, to achieving conservation success. The RWBJV Implementation Plan (RWBJV 2012*a*) outlines both short- and long-term conservation strategies that, if implemented, would further increase the kilocalorie production on WRP wetlands. More specifically, privately owned wetlands would provide approximately 50% of the forage resources for migrating waterfowl. At goal, the RWBJV partners plan to enroll an additional 4,050 ha of wetlands and 1,630 ha of upland buffer into long-term conservation programs by 2030 (RWBJV 2013*a*). Program flexibility will be important if these enrollment targets are to be met. For example, in 2010, the RWBJV partners were awarded a Wetlands Reserve Enhancement Program pilot that allowed landowners to retain the right to pass pivot irrigation sprinkler systems over the tracts enrolled in WRP due to the importance of irrigation for surrounding cropland not enrolled in WRP. With nearly 75% of the historical wetland footprints intersected by pivot irrigation systems, the assurances provided by the Wetlands Reserve Enhancement Program significantly increased interest and enrollment in the program. Continuing to provide this flexibility will be critical to meeting the enrollment benchmarks.

Over 60% of all surveyed points and vegetation map polygons on WRP properties were dominated by early successional habitats. The goal of land managers in the RWB is to achieve early successional habitats due to their high seed and kilocalorie production. Specific habitat quality target strategies were outlined in the RWBJV Implementation Plan (RWBJV 2013*a*) for lands enrolled in long-term conservation programs. This includes a target strategy that, on long-term private easements, early successional communities will comprise 75% of the habitat (RWBJV 2013*a*). To reach the goal of 75% early successional habitat, management actions that cause disturbance will need to be implemented to maintain early successional habitats. The RWBJV partners are working with agricultural producers who have lands enrolled in long-term conservation programs to establish infrastructure (e.g., perimeter fence, livestock watering facilities) that allow tracts to be incorporated into livestock operations. Providing economically viable management options will be critical if landowners and farm operators are going to be engaged in the management of tracts enrolled in WRP. Appropriate establishment of the grazing infrastructure will also promote desired habitat conditions while ensuring programmatic objectives can be met. Flexible, long-range (i.e., five-year plans) Compatible Use Authorizations will be important. These types of Compatible Use Authorizations will provide producers a level of certainty about their management options and maximize their engagement in management of the site.

In addition to on-site management actions, the RWBJV partners have committed to implement watershed restoration activities to maximize overland surface flow, which increases accessibility to the kilocalories produced on WRP sites and wetlands enrolled in other long-term conservation programs. One of the primary strategies is removal of irrigation reuse pits from the watersheds of these properties. With the shift from flood to pivot irrigation, many of these irrigation reuse pits are no longer needed; unfortunately, these pits must fill with precipitation before water can reach the wetland at the terminus of the watershed. Removing these irrigation reuse pits is a "win-win" by removing an obstacle from cropland, increasing cropland area, and facilitating water runoff to the associated wetland. The RWBJV partners also routinely work with county road departments to re-contour waterways and replace culverts to maximize volumetric flow to wetlands. To help meet the RWBJV target forage accessibility, a strategy RWBJV partners use is to work toward completing full hydrological restorations of all wetlands on conservation lands, which we recommend continuing.

An area of concern on WRP sites was the presence of invasive, monoculture-forming species and noxious weeds. These monoculture-forming species provide low habitat quality due to their low seed production and tendency to outcompete more desirable species. Reed canarygrass was of particular concern due to its prevalence, occurring at over 25% of surveyed long-term WRP points, and was the dominant vegetation at 13% of surveyed long-term WRP points and vegetation map polygons. Of the species listed as noxious weeds by the Nebraska Department of Agriculture, phragmites and musk thistle were observed on WRP wetlands. These two species were only present in small quantities at a few WRP sites each, but both species should be controlled while they are still uncommon and easier to manage and because landowners are legally obligated to do so.

RWB Conservation Lands Management

RWB wetlands provide crucial stopover habitat for migrating wetland-dependent birds. Given their importance and limited number, high-quality habitat conditions should be promoted on remaining RWB wetlands to provide sufficient kilocalories that will sustain target waterfowl and shorebird populations. The average annual amount of kilocalories accessible to waterfowl in ponded RWB wetlands was 1.3 billion kcal, far below the 4.4 billion kcal goal (RWBJV 2013*d*). For shorebirds, the 2012 accessible forage provided by RWB wetlands ranged from 13.9 million kcal to 33.9 million kcal, depending on the foraging guild, and must increase to support the target large-bodied probers and small-bodied prober/gleaner populations by 35.9 million kcal and 25.8 million kcal, respectively (RWBJV 2013*b*). These data illustrate the need for providing additional accessible forage in the region. To attain the target accessible kilocalories, conservation strategies must be implemented to produce additional kilocalories and provide ponded habitat that allows wetland-dependent birds to access the kilocalories produced.

Strategies to produce additional kilocalories in RWB wetlands include converting late successional and cropped wetland to early successional habitat as well as restoring non-functional cultivated wetlands to restored cropped wetland habitat. Providing early successional habitat is an important strategy because it produces the highest rate of energetic production for waterfowl and contains a high proportion of suitable habitat for shorebirds. A total of 55% of surveyed points and 58% of surveyed polygon area on RWB long-term conservation land wetlands were dominated by early successional communities. However, a conservation target identified in the RWBJV Implementation Plan is for public wetlands to contain 80% early successional communities and long-term private easement wetlands to contain 75% early successional habitats (RWBJV 2013*a*). One method for creating more early successional habitat, as discussed previously, is for land managers to convert late successional to early successional communities through management actions. Another option for increasing the area of early successional habitat is to increase the wetland area in long-term conservation programs through additional easement acquisitions. Enrollment in the conservation programs discussed in this report will help convert cropped wetlands to early successional habitat.

Restoring non-functional cultivated wetlands to restored cropped wetland habitat and protecting cropped wetlands from further drainage or degradation will help increase kilocalorie production because non-functional cultivated wetlands do not provide wetland foraging habitat for waterfowl or shorebirds, while cropped wetland habitats provide 100,000 kcal/ac for waterfowl and the highest proportion of suitable habitat for shorebirds. On behalf of the RWBJV, the Nebraska Association of Resources Districts recently submitted a Regional Conservation Partnership Proposal that would allow the Agriculture Land Easement option within the Agriculture Conservation Easement Program to be used to protect and restore cropped wetlands in the RWB. As proposed, agricultural producers would enroll tracts with hydrologically-modified wetlands that are routinely cropped. On the enrolled tract, a full hydrologic restoration would be completed and a perpetual easement would be placed on the tract. The easement would preclude any future wetland drainage as well as ensure the tract remains in agricultural production. The producer would be financially compensated for wetland restoration based on an appraised value. This option would provide producers an additional program for flood-prone cropland; allow cultivation during favorable weather patterns; and maximize habitat during migration, particularly for shorebirds.

For the forage produced in RWB wetlands to be accessible to wetland-dependent birds, the habitat must contain standing water. The second conservation strategy of providing additional ponded foraging habitat can be achieved through activities such as pumping water, restoring wetlands, and reestablishing watershed function (e.g., removing irrigation reuse pits). The importance of ponded habitat is demonstrated by the large amount of accessible forage (2.7 billion kcal) occurring in 2010, the year with the most early (i.e., 1 January–1 April) rainfall of any analyzed (Nebraska Rainfall Assessment and Information Network 2014). Because of the large annual variation in ponded area, conservation actions must provide sufficient kilocalories not just in the wettest years, but in drier years as well. Pumping activities are particularly beneficial in dry years because wetlands outside conservation lands are less likely to pond than in wetter years, making the additional habitat provided by pumping even more important.

Although pumping activities are beneficial, the solution is short-term and costly. To help alleviate the shortcomings of pumping, watershed and wetland hydrologic restoration should be used to provide additional wetland ponding. Watershed restoration, as described previously, allows additional runoff to reach the wetland and wetland hydrologic restoration allows water to pond in the wetland. Also, having conservation lands such as WRP in regions adjacent to the RWB will increase the likelihood that, if the RWB region is dry, weather patterns may provide ponded habitat nearby and allow wetland-dependent birds to move to areas that contain water.

In regards to our assessment, the RWBJV recognizes that the methods for estimating the RWB energetic production for shorebirds set forth in the RWBJV Shorebird Plan need further research to refine analyses (RWBJV 2013*b*). Currently, the Nebraska and Missouri Cooperative Fish and Wildlife Research Units are conducting research projects to answer key uncertainties outlined in the RWBJV Shorebird Plan (RWBJV 2013*b*). These studies will provide important data to refine the kilocalorie estimates. Current estimates do not take into account which areas are ponding water, but instead are based on a percentage of the total habitat type that is generally accessible to shorebird guilds, making the estimates less accurate. Also, the current kilocalorie/acre estimate does not vary by habitat type. Davis and Bidwell (2008) determined that farmed and reference RWB wetlands contained similar amounts of chironomid biomass, which is the invertebrate family from which the kilocalorie/acre estimate was derived. However, the total invertebrate biomass of farmed wetlands was significantly higher than reference wetlands (Davis and Bidwell 2008). The method for estimating the RWB accessible forage for waterfowl is much more robust than for shorebirds. However, future research to determine the annual variability of seed production by habitat type as well as assess the implications of management actions on seed production would help to create better estimates of kilocalorie production. By better understanding energetic production for shorebirds and waterfowl, the RWBJV partners will know more about what conservation actions must be implemented to manage for them.

ACKNOWLEDGEMENTS

We thank WRP landowners, without whom this project would not have been possible. We also thank J. Jirak with NRCS for helping us obtain access to WRP properties. For providing comments and edits to our draft report, we thank J. Jorgensen, S. Skagen, and E. Webb. DU, NGPC, and USFWS are thanked for allowing us to conduct surveys on their properties and, in the case of NGPC and USFWS, supplying field technicians to collect survey data. Funding was provided by an NRCS Wetlands Reserve Enhancement Program Technical Assistance Contribution Agreement (No. 68-6526-2-814), NRCS Conservation Effects Assessment Program Reimbursable Agreement (No. 67-3A75-14-0122), and Nebraska State Wildlife Grant (No. T-77-R-1). Finally, a huge thanks to our vegetation surveyors, C. Anderson, D. Cassidy, J. Drahota, E. Fredrick, S. Groepper, H. Johnson, C. Plihal, W. Rathman, A. Schole, and J. Westerby, for all of their help and long hours.

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APPENDIX A: SUPPLEMENTARY TABLES

Table A.1. Common waterfowl species and their scientific names that use the Rainwater Basin region of Nebraska.

Common Name	Scientific Name
Ducks	
American Wigeon	*Anas americana*
Blue-winged Teal	*Anas discors*
Gadwall	*Anas strepera*
Green-winged Teal	*Anas crecca*
Mallard	*Anas platyrhynchos*
Northern Pintail	*Anas acuta*
Northern Shoveler	*Anas clypeata*
Geese	
Canada Goose	*Branta canadensis*
Greater White-fronted Goose	*Anser albifrons*
Snow Goose	*Chen caerulescens*
Ross's Goose	*Chen rossii*

Table A.2. Common shorebird species and their scientific names in each of the analyzed shorebird guilds that use the Rainwater Basin region of Nebraska.

Common Name	Scientific Name
Small-bodied Probers/Gleaners	
Semipalmated Plover	*Charadrius semipalmatus*
Black-bellied Plover	*Pluvialis squatarola*
Spotted Sandpiper	*Actitis macularius*
Semipalmated Sandpiper	*Calidris pusilla*
White-rumped Sandpiper	*Calidris fuscicollis*
Baird's Sandpiper	*Calidris bairdii*
Pectoral Sandpiper	*Calidris melanotos*
Western Sandpiper	*Calidris mauri*
Large-bodied Probers	
American Avocet	*Recurvirostra americana*
Greater Yellowlegs	*Tringa melanoleuca*
Lesser Yellowlegs	*Tringa flavipes*
Hudsonian Godwit	*Limosa haemastica*
Willet	*Tringa semipalmata*
Stilt Sandpiper	*Calidris himantopus*
Long-billed Dowitcher	*Limnodromus scolopaceus*
Swimmers	
Wilson's Phalarope	*Phalaropus tricolor*

Table A.3. Cover types used for 2012 vegetation surveys of wetlands in the Rainwater Basin, Nebraska, and scientific names and 2012 vegetation map classes.

Cover Type	Scientific Name	Vegetation Map Class
Annual smartweed	*Polygonum* spp.	Moist-Soil Species
Arrowhead	*Sagittaria* spp.	Water
Bare soil	N/A	Bare Soil/Mudflat
Barnyardgrass	*Echinochloa* spp.	Moist-Soil Species
Broadfruit bur-reed	*Sparganium eurycarpum*	Moist-Soil Species
Bursage	*Ambrosia grayi*	Moist-Soil Species
Canada thistle	*Cirsium arvense*	Moist-Soil Species
Cattail	*Typha* spp.	Cattail
Dogbane	*Apocynum cannabinum*	Moist-Soil Species
Foxtail	*Setaria* spp.	Moist-Soil Species
Horseweed	*Conyza canadensis*	Moist-Soil Species
Kentucky bluegrass	*Poa pratensis*	Grass
Lambsquarters	*Chenopodium album*	Moist-Soil Species
Leafy spurge	*Euphorbia esula*	N/A
Mudflat (water under 3 inches)	N/A	Bare Soil/Mudflat
Musk thistle	*Carduus nutans*	Moist-Soil Species
Native warmseason grass	e.g., *Sorghastrum nutans*	Grass
Other annual desirable	e.g., *Coreopsis tinctoria*	Moist-Soil Species
Other perennial forb	e.g., *Rumex* spp.	Grass
Other perennial grass	e.g., *Elymus* spp.	Grass
Other undesirable	e.g., *Bromus tectorum*	Moist-Soil Species
Perennial smartweed	*Polygonum amphibium*	Moist-Soil Species
Phragmites	*Phragmites australis*	Reed Canarygrass
Pigweed	*Amaranthus* spp.	Moist-Soil Species
Pondweed or duckweed	*Potamogeton* spp. or *Lemna* spp.	Water
Purple loosestrife	*Lythrum salicaria*	N/A
Ragweed	*Ambrosia* spp.	Moist-Soil Species
Reed canarygrass	*Phalaris arundinacea*	Reed Canarygrass
River bulrush	*Schoenoplectus fluviatilis*	River Bulrush
Rush	*Juncus* spp.	Wet Meadow Species
Sedge or flatsedge	*Carex* spp. or *Cyperus* spp.	Wet Meadow Species
Smooth brome	*Bromus inermis*	Grass
Spikerush	*Eleocharis* spp.	Wet Meadow Species
Standing water (water over 3 inches)	N/A	Water
Sunflower	*Helianthus* spp.	Moist-Soil Species
Western wheatgrass	*Pascopyrum smithii*	Wet Meadow Species
Woody species	e.g., *Populus deltoides*	Woody Species

Table A.4. The number and percentage of survey points contained in each cover type for long-term Wetlands Reserve Program sites (WRP; *n* = 2,528), other long-term private easements (Other; *n* = 248), Wildlife Management Areas (WMA; *n* = 2,827), Waterfowl Production Areas (WPA; *n* = 6,821), and all sites combined (*n* = 12,424) in the Rainwater Basin, Nebraska. Data from vegetation surveys conducted at sites in 2012.

	WRP		Other		WMA		WPA		All	
	#	%	#	%	#	%	#	%	#	%
Annual smartweed	681	26.9	96	38.7	826	29.2	1578	23.1	3181	25.6
Arrowhead	11	0.4	12	4.8	43	1.5	4	0.1	70	0.6
Bare soil	418	16.5	65	26.2	674	23.8	1676	24.6	2833	22.8
Barnyard grass	321	12.7	53	21.4	383	13.5	542	7.9	1299	10.5
Broadfruit bur-reed	13	0.5	0	0.0	38	1.3	88	1.3	139	1.1
Bursage	148	5.9	2	0.8	166	5.9	425	6.2	741	6.0
Canada thistle	0	0.0	0	0.0	5	0.2	60	0.9	65	0.5
Cattail	123	4.9	18	7.3	145	5.1	440	6.5	726	5.8
Dogbane	14	0.6	0	0.0	6	0.2	7	0.1	27	0.2
Foxtail	57	2.3	15	6.0	53	1.9	89	1.3	214	1.7
Horseweed	234	9.3	13	5.2	56	2.0	19	0.3	322	2.6
Kentucky bluegrass	59	2.3	1	0.4	122	4.3	587	8.6	769	6.2
Lambsquarters	55	2.2	14	5.6	38	1.3	5	0.1	112	0.9
Leafy spurge	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Mudflat (water <3 in)	25	1.0	20	8.1	35	1.2	31	0.5	111	0.9
Musk thistle	7	0.3	0	0.0	2	0.1	7	0.1	16	0.1
Native warmseason grass	178	7.0	22	8.9	158	5.6	522	7.7	880	7.1
Other annual desirable	681	26.9	37	14.9	574	20.3	802	11.8	2094	16.9
Other perennial forb	544	21.5	11	4.4	415	14.7	978	14.3	1948	15.7
Other perennial grass	468	18.5	28	11.3	406	14.4	1132	16.6	2034	16.4
Other undesirable	108	4.3	20	8.1	78	2.8	203	3.0	409	3.3
Perennial smartweed	379	15.0	25	10.1	899	31.8	2052	30.1	3355	27.0
Phragmites	3	0.1	0	0.0	0	0.0	6	0.1	9	0.1
Pigweed	84	3.3	16	6.5	59	2.1	82	1.2	241	1.9
Pondweed or duckweed	1	0.0	5	2.0	46	1.6	16	0.2	68	0.5
Purple loosestrife	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Ragweed	671	26.5	50	20.2	915	32.4	1656	24.3	3292	26.5
Reed canarygrass	716	28.3	77	31.0	682	24.1	1897	27.8	3372	27.1
River bulrush	243	9.6	20	8.1	276	9.8	828	12.1	1367	11.0
Rush	78	3.1	3	1.2	34	1.2	77	1.1	192	1.5
Sedge or flatsedge	191	7.6	7	2.8	239	8.5	1055	15.5	1492	12.0
Smooth brome	118	4.7	1	0.4	165	5.8	405	5.9	689	5.5
Spikerush	398	15.7	11	4.4	243	8.6	650	9.5	1302	10.5
Standing water (water >3 in)	4	0.2	3	1.2	39	1.4	143	2.1	189	1.5
Sunflower	273	10.8	25	10.1	211	7.5	646	9.5	1155	9.3
Western wheatgrass	20	0.8	0	0.0	7	0.2	53	0.8	80	0.6
Woody species	38	1.5	1	0.4	28	1.0	130	1.9	197	1.6